Southern Resident Killer Whales at Risk: Toxic Chemicals in the British Columbia and Washington Environment

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2002

SOUTHERN RESIDENT KILLER WHALES AT RICK: TOXIC CHEMICALS IN THE BRITISH COLUMBIA AND WASHINGTON ENVIRONMENT

by

S.C.H. Grant and P.S. Ross

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LIST OF ACRONYMS, ABBREVIATIONS, AND UNITS

ACE-Asia	Aerosol Characterization Experiment-Asia
AMD	acid mine drainage
AOX	absorbable organic halides
APARE	Asia-Pacific Atmospheric Research Experiment
B.C.	British Columbia
BIEAP	Burrard Inlet Environmental Action Program
BOD	biological oxygen demand
CCEB	Commercial Chemicals Evaluation Branch
Cd	cadmium
CEPA	Canadian Environmental Protection Agency
Cl	chlorine
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CRD	Capital Regional District
CSOs	combined sewer overflows
Cu	copper
DBT	dibutyltin
DDAC	didecyl dimethyl ammonium chloride
DDT	dichlorodiphenyl trichloroethane
DFO	Department of Fisheries and Oceans
Dioxins (or PCDDs)	polychlorinated dibenzo-*p*-dioxin
EEM	Environmental Effects Monitoring
EPA	Environmental Protection Agency (U.S.)
ESA	*Endangered Species Act* (U.S.)
Fe	iron
FREMP	Fraser River Estuary Management Program
Furans (or PCDFs)	polychlorinated dibenzofuran
g	gram
GBEI	Georgia Basin Ecosystem Initiative
GPF	Georgia-Puget-Fuca System (the Strait of Georgia, Puget Sound, Juan de Fuca Strait)
GVRD	Greater Vancouver Regional District
H	Henry's law constant
ha	hectare
HCH	hexachlorocyclohexane
Hg	mercury
Hp	hepta
Hx	hexa
IGAC	International Global Atmospheric Chemistry Program
IPBC	3-iodo-2-propynyl-butyl carbamate
IPM	integrated pest management
ITCT	Inter-Continental Transport and Chemical Transformation Program

kg	kilogram
K_{ow}	octanol:water partition coefficient
kt	kilotonnes
L	litre
LRTAP	long range transport of atmospheric pollutants
lw	lipid weight
m	metre
MBT	monobutyltin
MeHg	methyl mercury
MELP	Ministry of Environment, Lands, and Parks
MFO	mixed function oxidase
mg	milligram
Mt	megatonnes
n	sample size
NASA	U.S. National Aeronautics and Space Administration
NGOs	nongovernmental organizations
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
O	octa
Pa	Pascal
PAHs	polycyclic aromatic hydrocarbon
Pb	lead
PBBs	polybrominated biphenyls
PBDEs	polybrominated diphenyl ethers
PBTs	polybrominated terphenyls
PCBs	polychlorinated biphenyls
PCNs	polychlorinated napthalanes
PCPs	polychlorinated paraffins
PCTs	polychlorinated terphenyls
Pe	penta
PEACAMPOT	Environment Agency of Japan's Perturbation by the East Asian Continental Air Mass to the Pacific Oceanic Troposphere program
PEM	Pacific Exploratory Mission
PFOS	perfluoro-octane sulfonate
POPs	persistent organic pollutants
rt	room temperature
s	second
SARA	*Species at Risk Act* (Canada)
Se	selenium
SWMP	Solid Waste Management Plan
t	tonnes
T	tetra
TBT	tributyltin
TCMTB	2-(thiocyanomethylthio) benzothiazole

TEF	toxic equivalency factor
TEQ	toxic equivalent quotient
TRACE-P	Transport and Chemical Evolution over the Pacific
TSS	total suspended solids
UC PacRim	University of California Pacific Rim Aerosol Network
μg	microgram
VEHEAP	Victoria and Esquimalt Harbours Environmental Action Program
WSU	Washington State University
WWTP	wastewater treatment plant
Zn	zinc

ABSTRACT

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Southern resident killer whales (*Orcinus orca*) have recently been described as "among the most contaminated marine mammals in the world", with levels of polychlorinated biphenyls (PCBs) exceeding those found in the St. Lawrence Beluga whales (*Delphinapterus leucas*). Killer whales are exposed to a myriad of anthropogenic contaminants, but those of particular concern include the Persistent Organic Pollutants (POPs). These oily chemicals, which include PCBs, dioxins, furans and dichlorodiphenyltrichloroethane (DDT), are persistent in the environment, bioaccumulate in aquatic food chains, and are toxic to biota. As a result of health risks thought to be associated with exposure to these and other toxic chemicals, as well as declining prey (salmon) abundance and heavy vessel traffic, Canada has listed this small population as "endangered"; a similar listing is pending in the United States. Documenting the sources of these chemicals to killer whales is an important basis for mitigative and regulatory steps for chemical usage, as well as precautionary conservation and management measures for the killer whales. Because of the large habitat requirements and high trophic level of killer whales, contaminants to which they are exposed can be considered of local, regional and international origin. The relative importance of regional sources in the Strait of Georgia and Puget Sound to the contamination of these killer whales is unknown, since contaminants can move great distances through biological, hydrological and atmospheric processes. We conducted a broad-based review of available scientific and technical information in order to characterize sources of contaminants that might accumulate in killer whale food chains. Killer whales are likely to face continued health risks associated with exposure to contaminants in the British Columbia - Washington boundary region as a result of the continued environmental cycling, production, release and transport of both "old" and "new" POPs in the North Pacific ecosystem.

RÉSUMÉ

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On a récemment décrit les épaulards résidents du Sud (*Orcinus orca*) comme "faisant partie des mammifères marins les plus contaminés au monde", leurs niveaux de biphényles polychlorés (BPC) dépassant ceux des bélugas du Saint-Laurent (*Delphinapterus leucas*). Les épaulards sont exposés à une multitude de contaminants anthropiques, dont certains posent une menace particulière, notamment les polluants organiques persistants (POP). Ces produits huileux qui incluent les BPC, les dioxines, les furannes et le dichlorodiphényltrichloréthane (DDT), sont persistants dans l'environnement, sont bioaccumulables dans les chaînes alimentaires aquatiques et s'avèrent toxiques pour le biote. À la lumière des risques pour la santé censément reliés à l'exposition à ces produits et à d'autres produits chimiques toxiques, du déclin de l'abondance des proies (saumon) et de l'intensité de la circulation maritime, le Canada a inscrit cette petite population à la liste des espèces "menacées de disparition"; une inscription similaire est en instance aux États-Unis. La documentation des sources des produits chimiques contaminant les épaulards est à la base des mesures d'atténuation et de réglementation de l'emploi des produits chimiques et aussi des mesures de précaution en matière de conservation et de gestion à prendre en faveur des épaulards. Étant donné l'immensité de l'habitat des épaulards et leur niveau trophique élevé, on considère que les contaminants auxquels ils sont exposés sont d'origine locale, régionale et internationale. Pour ce qui est du détroit de Georgia et du Puget Sound, on ignore l'importance relative des sources régionales dans la contamination des épaulards puisque les contaminants peuvent franchir de grandes distances par le biais de processus biologiques, hydrologiques et atmosphériques. Nous avons réalisé un examen généralisé de l'information scientifique et technique disponible afin de caractériser les sources de contaminants qui peuvent s'accumuler dans les chaînes alimentaires des épaulards. Il est probable que ces derniers vont continuer à faire face aux risques sanitaires associés à l'exposition aux contaminants dans la région frontalière de la Colombie-Britannique et du Washington du fait de la permanence du recyclage environnemental, de la production, de l'émission et du transport de POP à la fois "anciens" et "nouveaux" dans l'écosystème du Pacifique Nord.

1.0 EXECUTIVE SUMMARY

The southern resident killer whale (*Orcinus orca*) population is currently small (79 whales in 2001) and considered "endangered" in Canada. Unlike the northern resident population that has been growing at a relatively stable rate since the 1960s (Ford et al. 2000; Olesiuk et al. 1990), the size of the southern resident population has undergone significant fluctuations. In the 1970s, a reduction in the southern resident population size was due to the live capture killer whale fishery, with a slow recovery taking place following the cessation of this fishery. Recent reductions in the southern resident population are less understood, but a combination of factors have been suggested, including contaminant-related toxicity, declining prey abundance (salmon), and heavy vessel traffic, or a combination of these factors.

Killer whales are particularly vulnerable to accumulating Persistent Organic Pollutants (POPs) such as polychlorinated biphenyls (PCBs) and dichlorodiphenyltrichloroethane (DDT) as a result of their high trophic level, long life span and relative inability to eliminate many of these compounds. Very high levels of PCBs have been recently measured in southern resident killer whales. This population of fish-eating whales frequents the coastal waters of British Columbia (B.C.) and Washington State. Despite a similar diet, the southern residents have higher contaminant concentrations than those measured in northern resident killer whales that occupy coastal Alaska and northern B.C. waters, suggesting a "local" source of these contaminants. Other chemicals that may be more rapidly metabolized and eliminated by killer whales (e.g. dioxins, furans, and polycyclic aromatic hydrocarbons (PAHs)) may also pose a health risk through acute or chronic exposure. Exposure to PCBs and other POPs has been linked to a variety of health effects in marine mammals including endocrine disruption, reproductive impairment, immunotoxicity, and skeletal malformations.

Contaminants in southern resident killer whales likely reflect, in part, local (B.C./Washington) sources; contaminant 'hotspots' in their range generally include the major urban centers (e.g. Victoria, Vancouver, Seattle, Olympia, and Everett) and an assortment of industries (pulp and paper mills, mines, oil refineries). While contaminant point sources can result in locally elevated contaminant concentrations, non-point sources can distribute contaminants throughout the marine environment, thereby introducing contaminants into regions far removed from human activities. Atmospheric transport of contaminants has been found to be of great importance for POPs. Persistent Organic Pollutants enter the atmosphere through fossil fuel burning, municipal and industrial incineration, and through volatilization from water/terrestrial surfaces.

'Legacy' POPs will continue to present a health risk to killer whales over the coming decades as a result of a) their continued cycling in the environment; b) leakage from old disposal (e.g. landfills) and spill sites; c) by-production (e.g. dioxins) during incineration (combustion); d) occurrence in industrial and municipal discharges; and e) atmospheric delivery to the North Pacific food chain from countries where they are poorly regulated (e.g. parts of Asia). In addition, exposure to "new" chemicals with properties that are similar to old POPs (i.e. Persistent, Bioaccumulating and Toxic (PBT)) may increase as a result of limited regulation and increasing anthropogenic use.

In order to assess the risk of exposure by killer whales to contaminants of regional origin, we conducted a comprehensive review of existing information. In this report, we characterize 1) the key physico-chemical properties of contaminants that influence their environmental fate (persistence, volatility, solubility in water, and bioaccumulation potential); 2) the key atmospheric and oceanographic processes that govern the transport of contaminants through the environment; 3) the point and non-point sources of contaminants to the B.C. and Washington coastal marine environment that may present a health risk to killer whales; 4) the classes of "old" ("legacy") and "new" (i.e. poorly regulated) chemicals that might pose a health risk to southern resident killer whales.

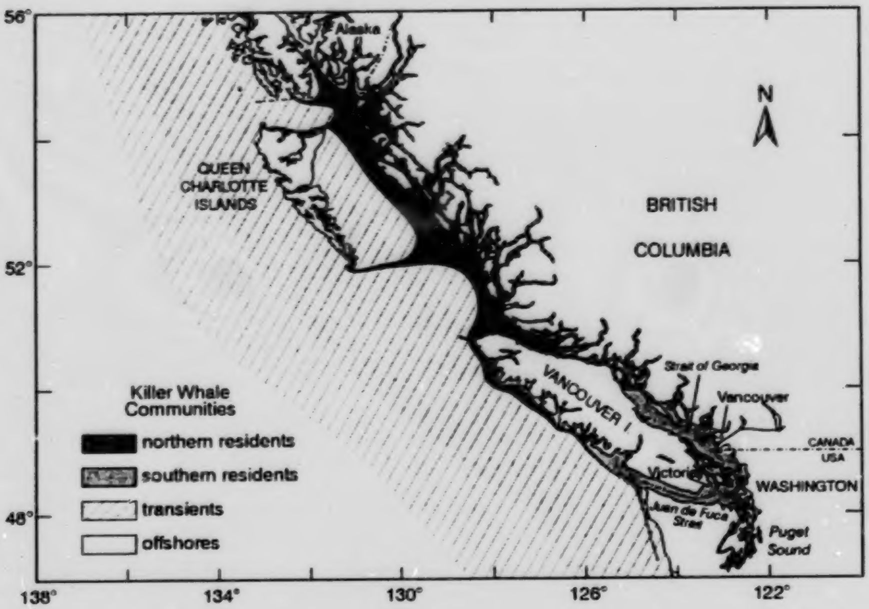
2.0 KILLER WHALES IN THE NORTHEAST PACIFIC OCEAN

2.1 KILLER WHALES

Killer whales are intelligent, social marine mammals found throughout the world's oceans. They occupy the top of marine food webs and apart from humans have no natural predators (Jefferson et al. 1991). Killer whale populations are organized into matrilineal groups -- females and their decedents -- that range in size from 4 - 12 individuals and span 2 - 4 generations (Ford et al. 2000). Generally, several matrilines associate together forming larger social groups called pods, with breeding only occurring between pods (Barrett-Lennard 2000).

Along the Pacific coast of North America, several genetically distinct populations of killer whales coexist, including the residents, transients, and offshores. Although there is much overlap of their ranges (Figure 1), these populations do not interbreed and have divergent behavior, morphology, acoustic repertoire, and social organization (Baird and Stacey 1988; Bigg et al. 1987; Ford and Ellis 1999). Perhaps the most ecologically significant feature distinguishing residents from transients is their diet; residents feed predominately on fish and transients feed predominantly on marine mammals (Ford et al. 1998). Less is known about the diet and behavior of the offshore population (Ford and Ellis 1999).

The resident population is further subdivided into two communities: the northern residents, that range from central Vancouver Island to southern Alaska, and southern residents, that range from northern Washington to southern B.C. The southern resident killer whales frequent the Strait of Georgia, Puget Sound, and Juan de Fuca Strait (Georgia-Puget-Fuca (GPF)) marine waters (Figure 1). Despite a partial overlap of their ranges, northern and southern residents do not associate with one another (Ford et al. 2000) and are genetically distinct (Barrett-Lennard 2000). The southern resident population is particularly vulnerable to extinction due to their small population size, slow rate of population growth, and the relatively high degree of anthropogenic activity occurring within their geographic range (Taylor 2001).


56°
52°
48°
138°
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130°
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122°
Alaska
N
QUEEN CHARLOTTE ISLANDS
BRITISH COLUMBIA
Strait of Georgia
Vancouver
VANCOUVER I
CANADA
USA
Victoria
WASHINGTON
Juan de Fuca Strait
Puget Sound
Killer Whale Communities
northern residents
southern residents
transients
offshores

Figure 1. Southern resident killer whales frequent the coastal waters of southern B.C. and Washington where human populations are concentrated. Source: (Ford et al. 1994).

2.2 SOUTHERN RESIDENT KILLER WHALES

2.2.1 Population Status

Currently, the southern resident killer whale population is extremely small (79 individuals total in 2002 and 3 pods: Ford 2002, pers. comm.) compared to the northern residents (200 individuals and 16 pods: (Ford et al. 2000)). Although the southern resident population size increased following the cessation of the live-capture fishery of killer whales in 1977 (Olesiuk et al. 1990), it decreased by 20 % between 1995 and 2002 (Figure 2)(Baird 1999)(Ellis 2001, pers. comm.). Since male and female killer whales do not reach maturity until they are 12 to15 years of age, and the number of offspring produced by females during their lifetime range from 4-6, population growth rates are slow.

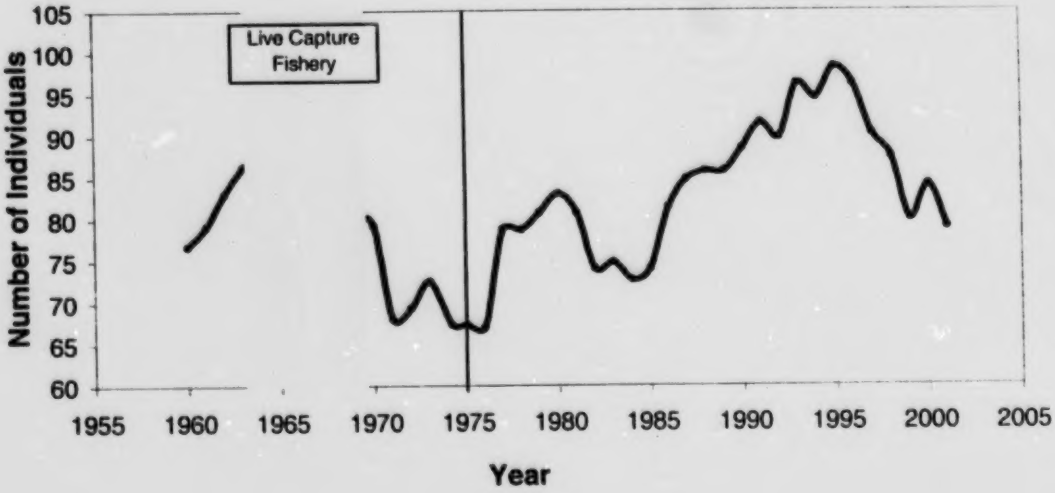


Figure 2. The causes of recent declines in the southern resident population are unclear. Data prior to 1975 are based on matrix model projections. Data from 1975 to 2002 are obtained from counts using photo-identification. Sources: (Baird 1999; Olesiuk et al. 1990; Ellis 2001, pers. comm.).

Based on differences in their mitochondrial and nuclear DNA, southern residents are reproductively isolated from other groups of killer whales (Barrett-Lennard 2000). Therefore, due to both their small population size, slow growth rates, and genetic isolation, factors that cause even slight changes in mortality or birth rates can have dramatic implications for the survival of the southern resident killer whale population. These factors, combined with the increasing anthropogenic activity taking place within the southern residents' range makes this population vulnerable to extinction. As a result, they were listed as "endangered" by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in November 2001. Once implemented, the *Species at Risk Act* (SARA) will provide COSEWIC with a legal status whereupon a recovery strategy and action plan must be developed for listed (endangered or threatened) species. In the U.S., a petition for the listing of southern resident killer whales as "endangered" under the *Endangered Species Act* (ESA) has been initiated by non-governmental organizations (NGOs).

Although natural factors (e.g. parasitism, disease, biotoxins, accidental beaching, and starvation) can impact the population, anthropogenic stresses appear to be increasing. These factors include 1) heavy vessel traffic (pleasure craft, ferries, freighters, and whale watching vessels); 2) prey availability (diminished salmon stocks through habitat destruction, fishing pressures, and reduced ocean survival of salmon associated with climate change); and 3) exposure to persistent toxic chemicals which bioaccumulate (Baird 1999; Ross et al. 2000; Taylor 2001).

This report focuses on exposure to persistent contaminants in the marine environment, of particular importance to biota that occupy high trophic positions such as the killer whales. In the North Pacific, persistent chemicals including dioxins, furans, and PCBs have been measured in the marine environment and in killer whales (Addison and Ross 2001; Calambokidis et al. 1990; Jarman et al. 1996; Ross et al. 2000).

The consumption of prey in the urbanized and industrialized areas of southern B.C. and of northern Washington may represent a particular concern for southern resident killer whales. The projected human population growth in this transboundary region (approximately 25% over the next 20 years), and associated increases in the use, application, and disposal of chemicals will likely represent a significant health risk to southern resident killer whales. In addition, human activities will increasingly affect terrestrial and aquatic environments, which may increase contaminant inputs into coastal waters through the alteration of contaminant pathways.

Contaminant exposure likely presents a significant health risk for southern resident killer whales as a result of their high trophic level, long lifespan, relative inability to eliminate POPs, and their reliance on habitat in heavily industrialized coastal regions of B.C. and Washington. Increasing urban and industrial development in the Georgia Basin/Puget Sound over the coming decades will likely place increasing pressure on marine environmental quality in this transboundary area. The relative risks presented to southern resident killer whales in the future will depend on the rates of reduction of "traditional POPs" (e.g. PCB and DDT) and the degree to which new chemicals (e.g. polybrominated diphenyl ethers or PBDEs) make their way into the marine food chain.

2.2.2 Diet

Although killer whales may be exposed to contaminants in air, water, and sediments, dietary intake represents the overwhelming route for exposure to the POPs, which are fat-soluble (Ross et al. 2000). Since many POPs can biomagnify in aquatic food chains (Muir et al. 1999; Norstrom and Muir 1994), southern residents, which occupy the top of the North Pacific food web, are particularly vulnerable (Figure 3) (Ross et al. 2000).

Knowledege of resident killer whale diets is restricted to the summer months (May to October) when observations of their feeding behavior are possible due to their known location (more inshore) at this time; in the winter months resident whales' ocean distribution is poorly known. Based on results from limited studies, resident killer whales feed on a variety of fish species, with salmonids estimated to make up the largest component of their diet. The predominant prey species is chinook (*Oncorhynchus tshawytscha*). Other salmonids, including coho (*O. kisutch*), sockeye (*O. nerka*), pink (*O. gorbuscha*), chum (*O. keta*), and steelhead (*O. mykiss*) salmon, also contribute to the diets of resident killer whales. Most other non-salmonid species in the resident killer whale diet are demersal (bottom dwelling) and include halibut and rockfish (Ford et al. 1998).

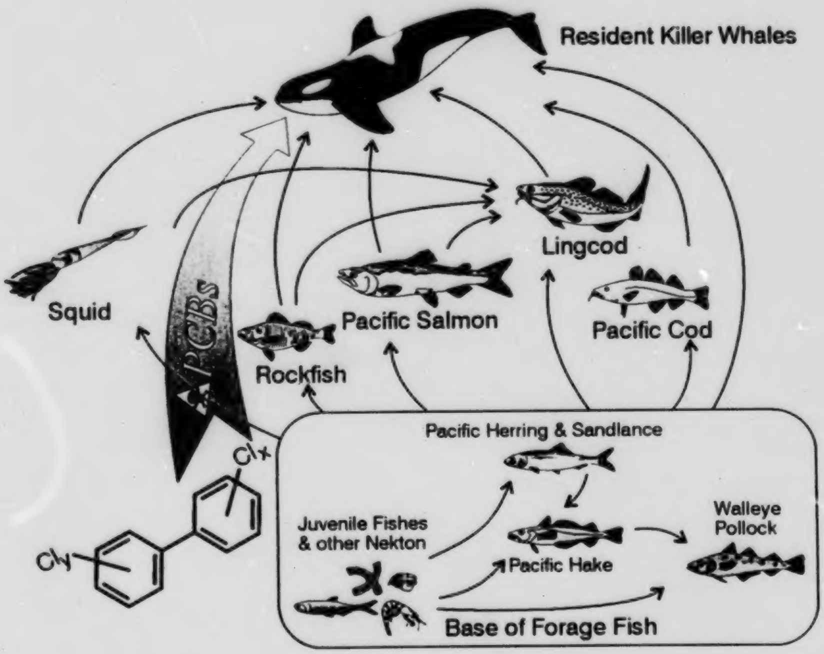

Resident Killer Whales
Lingcod
Squid
Pacific Salmon
Pacific Cod
Rockfish
PCBs
Pacific Herring & Sandlance
Juvenile Fishes & other Nekton
Walleye Pollock
Pacific Hake
Base of Forage Fish
Clx
Clx

Figure 3. Since resident killer whales occupy the top of the food web they can be exposed to high concentrations of bioaccumulative contaminants. Modified from (Ross and Troisi 2001).

2.2.2.1 Principal Prey (Salmonids)

Chinook salmon (*Oncorhynchus tshawytscha*) dominate the diet of killer whales, having a high fat and energy content. Although little is known of contaminant levels in chinook salmon from B.C., POPs have been measured in salmonids in Alaska and Washington (Ewald et al. 1998; O'Neill et al. 1998; Tetra Tech Incorporated 1996). Since chinook salmon are long-lived and feed predominantly on fish (Healey 1991), they occupy high trophic levels, and can therefore accumulate higher concentrations of POPs than lower trophic level salmonids (Kidd et al. 1982; Kidwell et al. 1995; Stow 1995). In Puget Sound, for example, PCB concentrations measured in adult chinook salmon muscle tissue ranged from 49.1 $\mu g \cdot kg^{-1}$ (wet weight (wet wt)) in fish collected from Puget Sound rivers to 74.2 $\mu g \cdot kg^{-1}$ (wet wt) in fish collected offshore from central and southern locations in the Puget Sound estuary (O'Neill et al. 1998).

The contaminant profile of chinook salmon reflects the suite of chemicals to which they have been exposed through feeding and growing in freshwater, estuarine, and open ocean environments. Chinook, like all Pacific salmon, are anadromous; they migrate to freshwater streams to spawn (average age of returning Fraser River chinook adults: 3-5 years) where their young hatch and develop before migrating to the ocean to grow to maturity (Healey 1991). Chinook are found in a number of B.C. and Washington streams, with the Fraser River accounting for most of their production. The residence time of chinook in different habitats vary with the life history characteristics of a particular stock. Stream-type chinook spend more than one year in freshwater and a short period of time in estuaries before migrating to the ocean. Ocean-type chinook spend less than one year in freshwater and longer times in estuaries before migrating to the ocean (Groot and Margolis 1991).

The marine residence of chinook salmon appears to contribute more significantly to their contaminant burdens than their freshwater residence. In adults returning to Puget Sound, freshwater residence accounted for only 1 % of the total PCB body burden, compared to marine residence that accounted for 99% (O'Neill et al. 1998; Varanasi et al. 1993; West et al. 2001a).

During their marine residence time, different salmonid stocks follow different migratory routes. Many stocks of chinook salmon leave the estuaries and migrate rapidly in a north west direction along the continental shelf before moving into the open ocean. Other stocks remain residents of coastal B.C. and Washington waters (O'Neill, Trudel & Welch 2001, pers. comm.); in Puget Sound, year-round residents have been artificially enhanced since the 1970s (Appleby and Doty 1995). Fish that remain year round in contaminated coastal regions may be expected to have higher contaminant burdens than fish that migrate directly to the open ocean.

For all life history types of chinook salmon, the location of their natal streams and their distribution in the estuarine and marine environment will affect their exposure to contaminants. Since southern Puget Sound has considerably higher concentrations of PCBs and other chemicals in sediments (Puget Sound Water Quality Action Team 1988) than northern Puget Sound and the Strait of Georgia, fish from southern streams may be more contaminated (O'Neill et al. 1998).

Although coho salmon comprise a smaller component of the resident killer whale's diet (Ford et al. 1998), due to their similar diet to chinook salmon (Groot and Margolis 1991), this species may also contribute significantly to the resident killer whales' overall contaminant burden. PCB concentrations measured in adult coho salmon muscle tissue ranged from 26.5 $\mu g \cdot kg^{-1}$ wet wt in fish collected from Puget Sound rivers to 35.1 $\mu g \cdot kg^{-1}$ wet wt in fish collected offshore from central and southern Puget Sound locations (O'Neill et al. 1998).

Sockeye, pink, chum, and steelhead salmon also comprise a small component of the resident killer whale diet (Ford et al. 1998). However, since these salmon species generally feed lower down the food web compared to chinook and coho, their contaminants loads and, therefore, their contribution to resident killer whales' contaminant burden, should be lower.

2.2.2.2 Minor Prey (Rockfish and Flatfish)

In addition to salmon, rockfish (*Sebastes* spp) and flatfish appear to comprise a small component of southern resident killer whale diets. Contrasting the large migration undertaken by salmonids, rockfish and flatfish remain resident in coastal marine habitats. Since rockfish have high site fidelity (Mathews 1990; West and O'Neill 1998) and have long life spans (Chilton and Beamish 1982), those inhabiting contaminated areas can be expected to accumulate higher concentrations of POPs than the salmonids. Although flatfish do not live as long as rockfish, they occupy the ocean bottom near the sediment surface where contaminants are concentrated.

From 1989-1999, average PCB concentrations (sum of Aroclor 1248, 1254, and 1260) in Puget Sound brown rockfish muscle tissue (214 $\mu g \cdot kg^{-1}$ wet wt) were higher than those measured in chinook salmon muscle tissue (54 $\mu g \cdot kg^{-1}$ wet wt) (West et al. 2001a). In Puget Sound, three species of rockfish have been monitored since 1989: the quillback rockfish (*Sebastes maliger*), the brown rockfish (*S. auriculatus*), and the copper rockfish (*S. caurinus*) (West et al. 2001a; West 1997; West and O'Neill 1998). PCB concentrations (sum of Aroclors 1254 and 1260) were higher in rockfish occupying urban/industrialized habitats of southern Puget Sound (Elliott Bay, Blakely Rocks, Sinclair Inlet; average concentration: 158 $\mu g \cdot kg^{-1}$ wet wt, muscle tissue) compared to the more remote habitats of central and northern locations (San Juan Islands and Admiralty Inlet; average concentration: 4.6 $\mu g \cdot kg^{-1}$ wet wt, muscle tissue) (West et al. 2001a; West and O'Neill 1998; West et al. 2001b).

A similar pattern was observed in Puget Sound english sole (*Pleuronectes vetulus*); higher PCB concentrations were found in fish frequenting urban marine waters compared to fish frequenting non-urban marine waters; muscle tissue PCB concentrations correlated with sediment PCB concentrations (O'Neill et al. 1998; Puget Sound Water Quality

Action Team 1988). The average PCB concentration in english sole muscle tissue between 1995-1999 was 40 $\mu g \cdot kg^{-1}$ wet wt (West et al. 2001a).

Contaminant profiles in resident fishes such as rockfish and flatfish likely reflect local hotspots of contamination, whereas the salmonids integrate contaminants from several different environments, many of which are far from human activities, over the course of their lifetime. As a result, while these demersal species only comprise a minor component of killer whale diet, their relative contribution to contaminant burdens in killer whales may be significant.

Southern resident killer whales are exposed to contaminants through their diet of salmon and other fish species. Little is known of the relative importance of different fish species to killer whale contaminant burdens. However, the sizable contribution of chinook salmon to resident killer whale diet suggests that POPs of open ocean origin are ending up in killer whales. Because some of the minor prey components of killer whale diet (e.g.rockfish) may reside in highly contaminated coastal environments (Puget Sound), they may contribute a disproportionately high proportion of the contaminants that accumulate in killer whales.

3.0 ENVIRONMENTAL CONTAMINANTS

3.1 ENVIRONMENTAL FATE OF CONTAMINANTS

Several properties of a chemical influence its fate in the environment and ultimately in killer whales. These include its persistence, volatility, solubility in water, and bioaccumulation potential (see Table 1). A chemical's persistence represents a key property, since a chemical that rapidly degrades in sunlight, water, or microbially will have only limited time to move through the environment and interact with biota; most POPs do not degrade rapidly in the environment. Persistence of a chemical is generally measured experimentally as the time it takes for half the amount of chemical initially present in water or soil to degrade (environmental half-life).

The volatility of a chemical determines its potential to evaporate and, therefore, be transported through atmospheric processes. Vapour pressure is used as a measure of the degree a chemical partitions into the gas phase. Conversely, the solubility of a chemical determines its potential to dissolve in water, and therefore, be transported in water (runoff or groundwater flow). Both the vapour pressure and water solubility of a chemical can be combined into a ratio called the Henry's Law constant (H) which describes air-water partitioning; chemicals with high H values more strongly partition to air and those with low H values more strongly partition to water. POPs exhibit a wide range of H values.

The final characteristic of a chemical that is particularly important to organisms that occupy high trophic positions is its ability to bioaccumulate. The octanol:water partition coefficient (K_{ow}) is a measure of the equilibrium distribution of organic contaminants between lipid and water phases. Chemicals with high K_{ow} values tend to be found at much greater concentrations in top predators than those with low K_{ow} values, relative to concentrations in the water column.

Table 1. A contaminant's physicochemical properties govern its environmental fate and hence the extent to which killer whales will be exposed.

Property	Environmental Consequence
Persistence	**Affects duration in environment after release**
Volatility	**Affects transport in the atmosphere**
Water Solubility	**Affects transport in rivers, runoff, and ocean currents**
Bioaccumulation Potential	**Affects concentrations at higher trophic levels**

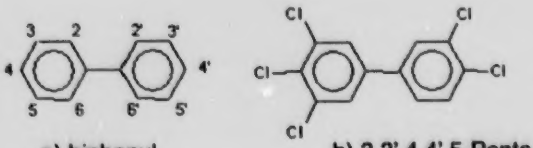
Based on their physicochemical and toxicological properties, numerous chemicals continue to present a health risk to marine biota despite their restricted use in developed nations including Canada and the U.S. Contaminant classes of concern include PCBs, dioxins/furans, PAHs, heavy metals, and pesticides.

The physicochemical properties of a contaminant, including persistence (environmental half-life), Henry's Law constant (H), and octanol:water partition coefficient (K_{ow}), govern fate in the environment, and ultimately, accumulation in killer whales.

3.2 CONTAMINANTS OF CONCERN

3.2.1 Polychlorinated biphenyls (PCBs)

Polychlorinated biphenyls (PCBs) consist of two phenyl rings (12 carbon atoms with 10 hydrogen and/or chlorine atoms) joined together through a carbon-carbon bridge (Figure 4). Variations in the number and position of chlorine atoms on the phenyl rings result in a total of 209 possible PCB congeners. Since PCBs are heat resistant and are good insulators they have been used as electrical transformer and capacitor fluids, flame retardants, hydraulic lubricants, sealants, paints, and pesticide extenders. Although tightly regulated in North America, PCBs continue to be used industrially and commercially in closed applications (e.g. in transformers and capacitors), they are also introduced to the environment from old landfills, incineration/combustion processes, municipal and industrial wastewater, and contaminated sediment or spill sites. The total amount produced world-wide is estimated at 1.5 million t (Rantanen 1992). Although not produced in Canada, 40 000 t of PCBs were imported from the U.S. prior to 1977, when U.S. PCB production and export was banned (Garrett and Goyette 2000).



a) biphenyl

b) 3,3',4,4',5-Penta CB

Figure 4. The chemical structure of a) a generic biphenyl (PCB) molecule and b) a PCB congener.

Several companies including Bayer (Germany), Kanegafuchi (Japan), Mitsubishi (Japan), Prodolec (France), and Monsanto (U.S.) produced PCBs in the past; continued production still occurs in less developed parts of the world. In North America, PCBs were manufactured solely by Monsanto (Canadian Council of Resource and Environment Ministers 1986). This company produced PCBs in different mixtures, marketed as Aroclors, that varied with degree of chlorination (Table 2). With the exception of Aroclor 1016, the last two digits in the Aroclor numbering system represent the mixture's weight percentage of chlorine. Different Aroclors dominated production and use in different years: the dominant Aroclor i) prior to 1950s was 1260; ii) from 1950s to 1960s was 1254; iii) in 1971 was 1016. Production and export of all Aroclors stopped in 1977, with a total of 700 000 t being produced during this time period (Ross & Associates Environmental Consulting 2000).

Table 2. PCBs were largely marketed as Aroclor mixtures (Monsanto) in North America, with different mixtures being composed of different groups of congeners with varying chlorine content.

Commercial Aroclor	Percent Chlorine		Percentage Congeners with Indicated Number of Chlorine Atoms									
			1	2	3	4	5	6	7	8	9	10
		Number of Isomers Possible Isomers	2	12	23	42	46	42	24	12	3	1
1232	32		26	29	24	14						
1016	41		2	19	57	22						
1242	42		3	13	28	30	22	4				
1248	48			2	18	40	36	4				
1254	54					11	49	34	6			
1260	60						12	38	41	8	1	

The physicochemical properties of PCBs vary with their degree of chlorination and the position of chlorine atoms. Highly chlorinated PCBs are more environmentally persistent than lower chlorinated PCBs. Higher chlorinated congeners do not partition into gas phase as strongly as lower chlorinated congeners and, therefore, are not transported as far in the atmosphere. Highly chlorinated PCBs (tetra- to nona-biphenyls) have a lower Henry's Law constant (H) that ranges from 5.6 to 8.2 $\text{Pa}\cdot\text{m}^3\cdot\text{mole}^{-1}$ than lower chlorinated PCBs (trichlorobiphenyls) that ranges from 24.3 to 92.2 $\text{Pa}\cdot\text{m}^3\cdot\text{mole}^{-1}$.

Since higher chlorinated PCB congeners have higher K_{ow} values (hexa- to nona-biphenyls: log $K_{ow} > 8$) compared to lower chlorinated congeners (mono- biphenyls: log $K_{ow} = 4.5$), these congeners may represent a greater concern in high trophic level biota due to their high bioaccumulation potential. Highly chlorinated PCBs also resist metabolism in biota, particularly in mammals, unlike lower chlorinated congeners that may be more readily metabolized and excreted. Metabolism of PCBs in mammals involves hydroxylation by the hepatic P-450 monooxygenase system. Hydroxylation increases the polarity of PCBs which increases their solubility necessary for excretion; this process occurs at unsubstituted *meta* (positions 3 or 5 on the phenyl rings) or *para* (position 4 on the phenyl rings) positions (Figure 4a). Metabolism of PCBs decreases with increasing number of chlorine atoms present and with decreasing number of adjacent unsubstituted carbon atoms. For example, 2,2',4,4',5,5'-hexachlorobiphenyl (PCB 153) is persistent, while 2,2',3,3',6,6'-hexachlorobiphenyl (PCB 136) is readily degraded and excreted in marine mammals (Boon et al. 1994; Boon et al. 1987; Boon et al. 1997).

Toxicological effects of PCBs on marine mammals may include reproductive impairment, skeletal deformities, endocrine disruption, and immunotoxicity (Bergman et al. 1993; Brouwer et al. 1989; DeSwart et al. 1996; Helle et al. 1976; Reijinders 1986; Ross 2000; Ross et al. 1996b). The most toxic PCBs are those with chlorine substitutions in the 3,3'4,4'-position (either non-*ortho***:** no chlorine substitutions at the 2 and 6 position on the phenyl rings; or mono-*ortho***:** one chlorine substitution at the 2 or 6 position) (Figure 4a) (de March et al. 1998). Non-*ortho* and to a lesser extent mono-*ortho* PCBs are particularly toxic since they can assume a flat (planar) conformation similar to dioxins and therefore exhibit similar toxic effects to these compounds. Since the effects of these planar PCBs on biota are comparable to those caused by 2,3,7,8-TCDD (dioxin), toxicity of these chemicals are often reported in relation to this reference compound in Toxic Equivalency Quotients (TEQs) using international Toxic Equivalency Factors (TEFs) (Van Den Berg et al. 1998).

PCB concentrations peaked in the 1960s and 1970s in different compartments throughout the industrialized world (sediment, water, soil, and biota), and subsequently declined after their use became strictly regulated (Garrett and Goyette 2000). Prior to their regulation, PCBs entered the environment through improper disposal, spills, accidental release, and direct discharges; in the U.S. an estimated 40% of total PCBs manufactured have been lost to the environment. Thirty-five percent of the historical global PCB production is estimated to exist in soils, plants, and aquatic ecosystems (Tanabe 1988). Although these chemicals can be removed from the water column through adsorption to particulates, sedimentation, and burial, PCBs can reenter the water column through remobilization becoming once again biologically available (Gevao et al. 1997; Oliver et al. 1989).

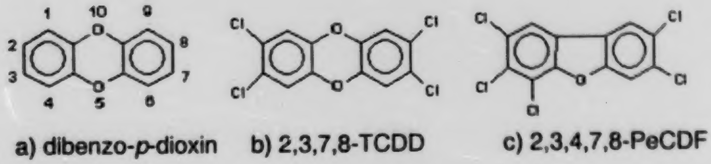
Although PCB concentrations have declined in the environment, they continue to be detected in marine biota globally (e.g. the St. Lawrence estuary, the Arctic, Europe, and the Mediterranean) (Blomkvist et al. 1992; Kannan et al. 2000; Muir et al. 1999; Muir et al. 1996). Recently, high levels of PCBs were measured in southern resident killer whales (males: 146 ± 33 $mg \cdot kg^{-1}$ lipid weight (lw); females: 55 ± 19 $mg \cdot kg^{-1}$ lw) compared to concentrations measured in northern resident killer whales (males: 37 ± 6 $mg \cdot kg^{-1}$ lw; females: 9 ± 3 $mg \cdot kg^{-1}$ lw) (Ross et al. 2000).

Although production of PCBs has been banned in North America, these chemicals continue to present a health risk to southern resident killer whales due to their persistence, strong bioaccumulation potential, and toxicity. Polychlorinated biphenyls

released in the past continue to cycle in the environment and continue to enter the B.C.-Washington environment from various regional sources including landfill sites, historical spill sites, incineration/combustion processes, and municipal and industrial wastewater discharges. In addition, atmospheric deposition into the North Pacific Ocean and regional coastal waters continues as a result of long range transport from distant sources. Concentrations of PCBs have largely stabilized since 1985, following the decrease that resulted from the implementation of regulations in the 1970s.

3.2.2 Dioxins and Furans

Polychlorinated dibenzo-*p*-dioxins (PCDDs or dioxins) and polychlorinated dibenzofurans (PCDFs or furans) consist of two phenyl rings (12 carbons and 8 hydrogen or chlorine atoms) joined together through one (furans) or two (dioxins) oxygen bridges (Figure 5). Dioxins and furans comprise a total of 75 and 135 congeners respectively, based on the number (total of 8) and position of chlorine molecules. These compounds have no commercial or domestic uses. Rather, they are created as unintentional by-products through combustion processes (incineration: hospital and municipal; low temperature combustion: fires and automobiles), through the production of chemical products (e.g. pesticides), and from industrial (pulp and paper mills: by-products of chlorine bleaching and from the combustion of wood chips contaminated with polychlorinated phenols) and natural (forest fires and volcanic activity) sources (Canadian Environmental Protection Act 1991), although mass-balance models and historical assessments of sediment cores suggest natural sources to represent a minimal impact into B.C. and Washington (Macdonald et al. 1998; Yunker and Cretney 2000a; Yunker and Cretney 2000b; Yunker et al. 2002).



a) dibenzo-*p*-dioxin b) 2,3,7,8-TCDD c) 2,3,4,7,8-PeCDF

Figure 5. The chemical structures of dioxins ((a) dibenzo-*p*-dioxin and (b) 2,3,7,8-tetrachlorinated dibenzo-*p*-dioxin) and furans ((c) 2,3,4,7,8-pentachlorinated dibenzofuran).

Dioxins and furans are extremely persistent in the environment; their half-life in anaerobic soils can range from 10-12 years and in sediments it can range from decades to centuries (Atkinson 1992). The estimated half-life of 2,3,7,8-tetrachlorinated dibenzo-*p*-dioxin (TCDD) in humans is from 5 – 7 years (Atkinson 1992). Dioxins and furans are nonvolatile and lipophilic. They bioaccumulate in biota, with increasing ability to bioaccumulate with the increasing degree of chlorination, ranging from a log K_{ow} of 4.75

in 1-chlorodibenzodioxin to a log K_{ow} of 8.2 in octachlorodibenzodioxin. Bioaccumulation factors for TCDD from water to aquatic organisms may range from 1 000 to 86 000 (Marty and Shusterman 1992).

Toxicological effects of dioxins and furans in mammals (e.g. laboratory rats and humans) include thymus and liver damage, birth defects, reproductive impairment, endocrine disruption, immunotoxicity and cancer (Murray et al. 1979; Government of Canada, Environment Canada, Health Canada 1993; Birnbaum 1994). The most toxic dioxins and furans are characterized by chlorine substitutions at the 2,3,7,8 positions (Figure 5a); 17 of the 210 dioxins and furans have chlorine atoms attached at these sites (Van Oostdam and Ward 1995). These 17 congeners have been assigned Toxic Equivalency Factors (TEFs); the most potent, 2,3,7,8-TCDD, has been assigned a TEF of 1 and the other 16 congeners have different TEFs based on their relative "dioxin-like" potential (Table 3). All other non-toxic dioxins and furans are assigned a TEF of 0. To calculate the TEF for mixtures of dioxins and furans, TEF values for the individual compounds are multiplied together to obtain a value for the mixture as a whole (Van Den Berg et al. 1998; Van Oostdam and Ward 1995; Yake et al. 1998).

Table 3. Toxicity Equivalency Factors (TEFs) have been assigned to dioxins and furans based on their relative toxicity to 2,3,7,8-tetrachlorinated dioxin. Source: (Van Den Berg et al. 1998).

Toxic Congeners	I-TEF
Dioxins	
2,3,7,8-TCDD	1
1,2,3,7,8-PeCDD	1
1,2,3,4,7,8-HxCDD	0.1
1,2,3,7,8,9-HxCDD	0.1
1,2,3,6,7,8-HxCDD	0.1
1,2,3,4,6,7,8-HpCDD	0.01
OCDD	0.0001
Furans	
2,3,7,8-TCDF	0.1
2,3,4,7,8-PeCDF	0.5
1,2,3,7,8-PeCDF	0.05
1,2,3,4,7,8-HxCDF	0.1
1,2,3,7,8,9-HxCDF	0.1
1,2,3,6,7,8-HxCDF	0.1
2,3,4,6,7,8-HxCDF	0.1
1,2,3,4,6,7,8-HpCDF	0.01
1,2,3,4,7,8,9-HpCDF	0.01
OCDF	0.0001

T=tetra; Pe=penta; Hx=hexa; Hp=hepta; O=octa

Pulp and paper mills represented important sources of dioxins and furans to coastal environments in the past. However, 1992 regulation of dioxins and furans in pulp and paper mill effluent in Canada and the U.S. has resulted in dramatic reductions in their concentrations in effluents discharged to marine ecosystems (Figure 6) (Environment Canada and Federal/Provincial Task Force on Dioxins and Furans 1999; Yake et al. 1998). Combustion processes now represent the greatest source of dioxins and furans to the regional environment (Figure 6); the total atmospheric release of dioxins and furans in B.C. was 9.3 g TEQ in 1999 (Environment Canada 2001) and in Washington was 4 g TEQ in 1998 (Yake et al. 1998). The burning of salt laden wood (46%), municipal incinerators (33%), and residential wood and wood waste combustion (17%) represent the largest sources of atmospheric releases to the B.C. environment (Environment Canada and Federal/Provincial Task Force on Dioxins and Furans 1999).

In addition to atmospheric releases, dioxins and furans are being or have been introduced directly to soil (Figure 6) as contaminants in pesticides (2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T)), sewage sludge in agriculture, chlorophenol treated wood (utility poles, railway ties, and heavy duty wood preservation plants), and disposal in landfills. Levels of dioxins and furans in soil adjacent to chlorophenol treated wood have been measured as high as 3 055 ng·kg^{-1} TEQs, considerably higher than background soil levels of 5 ng·kg^{-1} TEQs (Van Oostdam and Ward 1995). These terrestrial sources can enter the coastal marine environment via surface runoff.

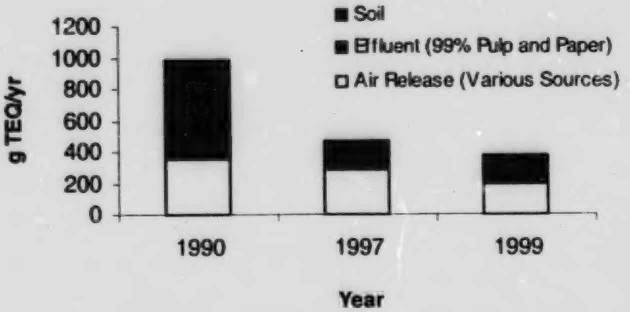


Figure 6. Currently the greatest sources of dioxins and furans to the environment are from atmospheric releases and soil deposition. Source: (Environment Canada and Federal/Provincial Task Force on Dioxins and Furans 1999).

Low concentrations of dioxins and furans have been detected in marine mammals globally (e.g. North America, the St. Lawrence Estuary, and Finland) (Jarman et al. 1996; Koistinen et al. 1997; Muir et al. 1996). These chemicals have also recently been measured in resident killer whales (average 1000 ng·kg^{-1} lw) (Ross et al. 2000). The lack of significant differences between concentrations of these chemicals in northern versus southern residents or between males and females, suggests that killer whales are able to metabolically eliminate these planar compounds (Boon et al. 1997; Ross et al. 2000).

Although dioxins and furans are largely eliminated metabolically by killer whales, they may cause toxicological effects through acute exposure or the formation of toxic metabolic intermediates. In the past, liquid wastewater discharged from pulp and paper mills represented the dominant source of dioxins and furans to the marine environment in British Columbia, but regulations led to dramatically reduced discharges. In recent years, municipal and industrial incineration and subsequent deposition into the marine environment have been a more significant source of these contaminants.

3.2.3 Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are organic molecules comprising two or more fused aromatic rings (each possessing 5-6 carbon atoms) (Figure 7). Different PAHs compounds contain different alkyl groups (or other radicals) in the ring structure. There are 100 different PAH compounds that are grouped according to their number of aromatic rings: low molecular weight PAHs (less than four rings) and high molecular weight PAHs (greater than four rings). PAHs are largely produced through combustion processes, but are also present in petroleum products (gasoline, oil, diesel). Natural releases occur during forest fires (2000 t per year in Canada in 1990) and volcanic eruptions (Government of Canada et al. 1994). Anthropogenic sources include fuel combustion, aluminum smelting (925 t per year in Canada in 1990), creosote-treated products (2000 t per year in Canada in 1990), oil spills (76 t per year in Canada in 1990), and metallurgical and coking plants (4 t per year in Canada in 1990) (Table 4) (Government of Canada et al. 1994). Pulp and paper mills and saw mills also produce PAHs, although their contribution is largely unknown (Yunker et al. 1999). For the Strait of Georgia, the Fraser River has been identified as the major source of PAHs (Yunker et al. 1999).

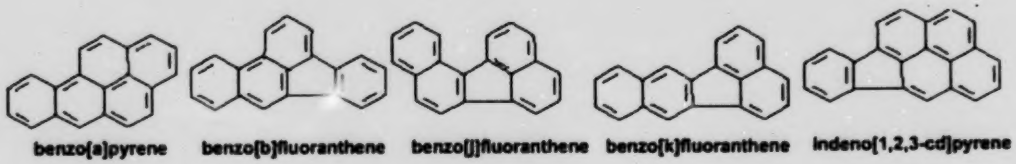


Figure 7. The chemical structures of five toxic PAH compounds.

PAHs are relatively persistent, particularly after burial in sediments (half-life for naphthalene ranges from 0.3 to 129 days). Overall, the physicochemical properties of PAHs reflect their molecular weight and structure; PAHs typically have low vapour pressures (non-volatile), low water solubilities, and high K_{ow}, with the exception of naphthalene which has a higher vapour pressure, high water solubility, and a lower K_{ow} (Table 5). Upon release to the atmosphere PAHs generally associate with particles suspended in the air and are transported until deposition (wet or dry deposition) onto water or soil surfaces or until they undergo chemical transformation. Sediments represent the final sink for PAHs in the marine environment (Murphy et al. 1988), although small amounts of resuspension can occur (Larsen et al. 1986; Murphy et al. 1988).

Despite their high K_{ow}, PAHs do not readily bioaccumulate in all organisms. In mammals, they are metabolized by the hepatic cytochrome P-450 mixed-function oxidase (MFO) system and epoxide hydrolase. The principal effects of PAHs are related to their carcinogenic potential. Liver tumours and other diseases have been observed in fish residing in locally contaminated environments (e.g. harbours) (Collier et al. 1998; Vethaak et al. 1996). Five PAHs are considered human carcinogens, including (benzo [*a*] pyrene, benzo [*b*] fluoranthene, benzo[*j*] fluoranthene, benzo[*k*] fluoranthene and indeno [*1,2,3-cd*] pyrene (Table 5) (Government of Canada et al. 1994).

Although no studies have been carried out on killer whales, studies on other marine mammals suggest that PAHs are likely metabolized and excreted by killer whales (Hellou et al. 1990; Hellou et al. 1991). Low levels of PAHs, however, have been detected in marine mammals globally (e.g. St. Lawrence Estuary, Atlantic Ocean) (Hellou et al. 1990; Hellou et al. 1991; Martineau et al. 1994). Biota in harbours (e.g. Vancouver harbour) have elevated PAH concentrations ranging from <0.001 to 0.16 $\mu g \cdot L^{-1}$ for English sole (*Parophris vetulus*) liver (Goyette and Boyd 1989), highlighting the potential for sporadic and short term exposures by killer whales frequenting the industrialized waters of Puget Sound, Juan de Fuca Strait, and the Strait of Georgia.

Although PAHs are likely metabolically eliminated by killer whales, they may cause adverse health effects through the consumption of contaminated prey. Fossil fuel burning continues to release large quantities of PAHs into the B.C. and Washington atmosphere. Together with other inputs, the deposition of atmospheric PAHs into the marine environment largely represents a localized contamination issue. PAH contamination in the marine environment typically occurs in sediments near harbours; fish at these sites have elevated PAH concentrations and, as a result, represent a possible dietary source of PAHs for killer whales.

Table 4. PAHs are released to the Canadian environment in large quantities from a variety of anthropogenic and natural sources. Source: (Government of Canada et al. 1994).

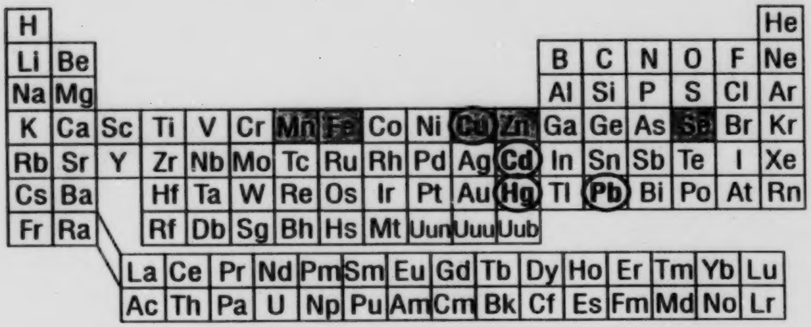
Sources	Tonnes	%
Anthropogenic Sources		
Industrial Processes		
Aluminum plants	925	21
Metallurgical	19.5	0.4
Coke production	12.8	0.3
Petroleum refineries	2.5	0.1
Combustion Sources		
Residential Heating		
Wood	474	11
Others	29	0.7
Open air fires/agricultural burning	358	8.3
Incineration		
Teepee burners	249	5.8
Municipal (with sludges)	1.3	<0.1
Industrial	1.1	<0.1
Transportation		
Diesel	155	3.6
Gasoline	45	1
Others	1.2	<0.1
Thermal Power Plants	11.3	0.3
Industrial Combustion		
Wood	5.7	<0.1
Others	10.2	0.2
Commercial and Institutional Heating	2.7	0.1
Cigarettes	0.2	<0.1
Natural Sources		
Forest Fires	2010	47
Total	**4314**	**100**

Table 5. PAHs have low vapour pressures, low water solubilities, and high Kow, and are persistent in anaerobic sediments. Source: (Government of Canada et al. 1994).

Compound	**Molecular Weight**	**log Kow**	**Water Solubility (25°C) (mg/L)**	**Vapour Pressure (25°C) (mPa)**
naphthalene	128	3.5	31.7	11960
acenaphthene	154	4.33	3.42	594
fluorene	166	4.18	1.98	95
phenanthrene	178	4.5	1.29	91
anthracene	178	4.5	0.045	25
pyrene	202	4.9	0.135	91.3×10^{-6}
fluoranthene	202	5.1	0.26	1328
benzo[*a*]anthracene	228	5.6	0.0057	14.7×10^{-3}
benzo[*a*]pyrene	252	6	0.0038	0.4×10^{-6}
benzo[*b*]fluoranthene	252	6.06	0.014	0.1×10^{-5} to 0.1 (20°C)
benzo[*k*]fluoranthene	252	6.06	0.0043	2.8×10^{-9}
indeno[*1,2,3-cd*]pyrene	276	6.4	0.00053	1.3×10^{-5}

3.2.4 Heavy Metals

Although metals are natural elements in the environment, their concentrations can be enriched in certain areas or organisms as a result of human activities. Common anthropogenic sources of metals to the marine environment include mines, metal refineries, landfill leachate, sewage treatment plants, and urban runoff. Certain metals such as copper (Cu), zinc (Zn) and iron (Fe) are essential to the nutrition of animals while other metals such as mercury (Hg) and lead (Pb) are not (Figure 8). Although all metals can be toxic at high concentrations, cadmium (Cd), Hg, Cu, and Pb are particularly toxic even at low concentrations.



H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub						
		La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	
		Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	

Figure 8. Periodic Table of the Elements; "essential metals" are shaded dark grey, "non-essential" metals are shaded light grey, and toxic metals are circled.

Upon entry into the marine environment, most metals adsorb to suspended particulates and settle to the ocean floor where they become incorporated into the sediments. Metals are generally concentrated in sediments near large urban centres, harbours, and mines and metal refineries, and can therefore present local risks to the environment. In anoxic (oxygen poor) sediments where hydrogen sulphide is present, most metals are bound in the sulphide form and therefore remain unavailable to biota. However, metals can reenter the water column if the sediments become disturbed and are exposed to oxygen. Benthic organisms (bioturbation), dredging, and strong oceanographic mixing represent factors that contribute to the remobilization of metals from the sediments. Marine biota can therefore be exposed to metals long after they enter into the marine environment.

3.2.4.1 Cadmium (Cd)

Cadmium (Cd) is a metal (Figure 8) which can originate from both natural and anthropogenic sources in the environment. As a transition metal, it has valence electrons (electrons used to combine with other elements) present in more than one shell and can therefore occur in several oxidation states. Cd occurs in the environment in its inorganic form as Cd chloride, -oxide, -sulphide, -sulphate; organocadmium compounds have not been detected in the environment (Nriagu and Pacyna 1988; Yeats and Bewers 1987). Anthropogenic releases to the atmosphere are largely from smelting of base metal ores (65-85%), fossil fuel combustion, sewage sludge application, and solid waste incineration. Cadmium may also be released to the marine environment in leachate from landfills (disposal of batteries, pigments, plastics, televisions) (Government of Canada et al. 1993b). Global anthropogenic releases of Cd are estimated at between 3 100 t and 12 000 t annually (Nriagu and Pacyna 1988; Yeats and Bewers 1987). Natural sources of Cd include weathering of Cd bearing rock, forest fires, volcanic activity and upwelling processes in the ocean.

Although Cd does not degrade in the environment, physico-chemical processes influence its residence time in the environment (Government of Canada et al. 1993b). In the atmosphere, Cd compounds (chloride, oxide, sulphide, and sulphate) are not volatile but occur associated with particulates and, as a result, can be rapidly removed by wet and dry deposition. Cd and several of its compounds including cadmium oxide, cadmium sulphide, and cadmium carbonate are insoluble in water and therefore tend to be rapidly removed through sedimentation. Cd can be remobilized from the sediments and reenter the water column through redox mediated reactions (natural chemical process of reduction and oxidation) (Government of Canada et al. 1993b).

Exposure to high concentrations of different Cd compounds (cadmium chloride, oxide, sulphide) can cause reductions in growth, immune impairment, renal dysfunction, and cancer in mammals (Government of Canada et al. 1993b). Acute exposure can lead to dystrophic changes of the liver, heart, kidneys, and necrosis of the gastric and intestinal mucosain in vertebrates. In the kidney or liver of marine mammals, Cd can combine with selenium (Se) to form a Cd-Se complex and Cd can also be incorporated into a metallothionein complex, both of which are non-toxic forms of Cd (Augier et al. 1993; Skaare et al. 1994; Wagemann and Stewart 1994).

High levels of Cd have been identified in marine biota in different parts of the world. Species with renal Cd levels exceeding 50 mg $Cd \cdot kg^{-1}$ include Atlantic pilot whales (*Globicepheala melaena*) off Newfoundland (Muir et al. 1998), harp seal (*Phoca groenlandica*) in the Gulf of St. Lawrence (Wagemann et al. 1988), and ringed seal (*Phoca hispida*) near Baffin Island (Wagemann 1989). One population of narwhal (*Monodon monoceros*) near Baffin Island have an average of 75 mg $Cd \cdot kg^{-1}$ in their kidney, which may be sufficiently high to cause sublethal toxicity in these animals (Muir et al. 1999). Cadmium has also been detected in seabirds from the B.C. coast; relatively high concentrations of Cd (306 ± 78 $mg \cdot kg^{-1}$ dry wt (kidneys)) were measured in Leach's storm-petrels (*Oceanodroma leucorhoa*) in the Queen Charlotte Islands (Elliott and Scheuhammer 1997).

3.2.4.2 Mercury (Hg)

Like Cd, mercury (Hg) is also a transition metal (Figure 8) that originates from both natural and anthropogenic sources, and can occur in elemental, ionic, or methylated form. Mercury is currently used in gold mining activities, anti-fouling paints, laboratory instruments, and electrical equipment (World Health Organization 1990). Most Hg of anthropogenic origin enters the environment through atmospheric emissions of elemental or oxidized Hg, from coal-fired power plants, municipal waste combustors, medical waste incinerators, and hazardous waste combustors (Keating et al. 1997; Rice et al. 1997). Mercury can also be discharged directly to the aquatic environment through municipal or industrial wastewaters. Global anthropogenic production of Hg exceeds 100 000 t annually (95% inorganic Hg), with considerable quantities released into aquatic and atmospheric environments (Nriagu 1979; Nriagu and Pacyna 1988). Anthropogenic Hg production is 2-3 times greater then natural production (Mason et al. 1994). Re-emissions from soils, sediments and vegetation also contributes to substantial loading of Hg.

Elemental mercury is volatile and can have long residence times (< 1 yr) in the atmosphere, this form of mercury can therefore be transported long distances in the atmosphere (Rice et al. 1997). Cloud moisture can convert atmospheric elemental mercury to its oxidized state which is rapidly removed from the atmosphere and deposited onto land and water surfaces (Rice et al. 1997). In water, since Hg is insoluble and adsorbs to organic particulates, it rapidly settles out of the water column; sediments therefore serve as an important Hg reservoir (Rice et al. 1997). Depending on its form (elemental, ionic, or methylated), Hg exhibits environmental mobilities and toxicities (Macdonald and Bewers 1996). Methylmercury (MeHg) is the most bioavailable form of mercury and is capable of reaching high concentrations as a result of its ability to bioaccumulate. Methylmercury is the most toxic form of Hg; it causes neurological damage in humans and can also be fatal at high doses (McMurtry et al. 1989; World Health Organization 1990). The developing fetus is most sensitive to MeHg toxicity; fetal exposure to Hg can cause neurological abnormalities (Hassett-Sipple et al. 1997). In adult marine mammals, MeHg is usually comprises a small percentage of the total Hg body burden (Becker 2000); Hg combines with Se to form a less toxic Hg-Se complex and is stored in the liver (Becker 2000). Marine mammals also can de-methylate MeHg, converting it to less toxic inorganic Hg and excreting this form (Becker 2000).

Although localized Hg releases to the aquatic environment have been reduced in recent years in response to emission restrictions, elevated concentrations of Hg above background levels may continue for decades (Lodenius 1991). The continued burning of coal represents an important source for Hg on a global scale (Macdonald et al. 2000a; Nriagu 1991).

Mercury has been detected in marine biota around the world, reflecting a combination of natural and anthropogenic sources. Mercury concentrations in beluga whale (*Delphinapterus leucas*) liver in the Alaska Arctic ranged from 1.40-72.9 $\mu g \cdot \cdot g^{-1}$ wet wt, similar to concentrations (20 $\mu g \cdot g^{-1}$ wet wt) measured in pilot whale (*Globicephala melas*) liver in the North Atlantic (Becker et al. 1995). Concentrations of Hg have also been detected in seabirds collected along the west coast of Vancouver Island, B.C.; concentrations in Leach's storm-petrels were on average 6.37 $\mu g \cdot g^{-1}$ (dry wt)(Elliott and Scheuhammer 1997).

3.2.4.3 Copper (Cu) and Lead (Pb)

Other metals in the marine environment that may be of concern to killer whales include copper (Cu) and lead (Pb) (Figure 8). While both metals are generally found at low concentrations throughout the ecosystem, anthropogenic processes and activities have resulted in elevated concentrations both locally and globally. Copper is an ingredient in fungicides, insecticides, and wood preservatives and can enter the marine environment from atmospheric transport or from terrestrial runoff. Anthropogenic loads of Cu to the global environment are estimated at 20 000 to 51 000 t per year (Mason et al. 1995; Nriagu and Pacyna 1988; Pacyna 1995). Lead was widely used in leaded gasoline (60%) between 1920 and 1990; after 1990 its use was phased out in Europe, Canada, and the U.S. Lead continues to be released from smelters and refineries. Anthropogenic loadings of Pb to the environment, globally, are estimated at between 288 000 and 376 000 t per year (Mason et al. 1995; Nriagu and Pacyna 1988; Pacyna 1995).

Toxicological effects in mammals associated with exposure to high concentrations of Cu include genetic abnormalities, developmental abnormalities (skeletal and soft-tissue malformations), and renal failure. Toxicological effects associated with exposure to high concentrations of Pb include hypertension, reproductive disorders, neurological and metabolic problems. Since Pb is similar to calcium it can accumulate in bones and can be released with calcium into the bloodstream. Long-term exposure to Pb can cause impaired mental function, neurological damage, kidney dysfunction, and anemia.

Both Cu and Pb are generally detected in sediments near point sources including urban/industrial areas and sites of acid mine drainage and smelters. Low concentrations of Cu and Pb have been detected in marine mammals globally (Becker 2000; Muir et al. 1998; Wagemann 1989).

In marine mammals, metals generally do not bioaccumulate and may be detoxified and/or eliminated. However, chronic exposure to metals such as mercury, cadmium, copper, and lead, may present a moderate and/or localized health risk to killer whales. Most metals are a localized environmental concern; concentrations tend to be elevated near large urban and industrial centres where discharges are concentrated.

3.2.5 Pesticides

Pesticides are used to control insects (insecticides), weeds (herbicides), and fungi (fungicides) in urban, agricultural, and forestry settings. These chemicals are generally applied to the terrestrial environment but can be transported to adjacent aquatic environments via surface runoff or ground water discharge during rain events or aerial spray drift (Figure 9) (Majewski and Capel 1995). Pesticides entering the aquatic environment from urban sources include combined sewer overflows (CSO), landfill leachate, urban runoff, and municipal wastewater treatment plants (ENKON Environmental Limited 1999). Persistent pesticides may be transported in streams and the atmosphere to distant aquatic ecosystems including the ocean. Some pesticides can also be used directly in aquatic ecosystems such as organotins which are used on ships as anti-fouling agents (see Section 6.4.3).

Depending on environmental conditions, pesticides that accumulate in sediments and aquatic biota tend to have a soil half-life greater than 30 days, a water solubility less than 1 milligram per liter, and a log K_{ow} greater than 3 (Nowell et al. 1999). Although currently used pesticides are not as potent as the more regulated organochlorine pesticides, some are moderately persistent, bioaccumulative, and toxic (Table 6). Although now largely banned (Table 7), organochlorine pesticides (e.g. aldrin, dieldrin, chlordane, DDT, alpha-hexachlorocyclohexane (α–HCH), and toxaphene) represent an ongoing environmental concern since they are highly persistent, bioaccumulative and toxic (Table 8). Toxicological effects of these compounds in mammals may range from reproductive impairment, developmental effects, immunosuppression, cancer, and adrenal and thyroid effects (Table 9).

Prior to its regulation in the early 1970s in Canada and the U.S., DDT had negative effects on bird populations by reducing egg shell thickness and subsequent hatching success (Calambokidis et al. 1985; Cooke 1973; Enderson et al. 1982; Gress et al. 1973; Hickey and Anderson 1968; Nelson and Myres 1976; Pearce et al. 1979; Wesoloh et al. 1983). DDT reduces egg shell thickness through its breakdown product, dichlorodiphenyldichloroethylene (DDE), which interferences with calcium carbonate production in birds; egg shells with less calcium carbonate are thinner and more likely to break before a bird is adequately developed for hatching (Government of Canada 1996). After DDT was banned, its concentrations in bird eggs declined in Strait of Georgia populations breeding near contaminant sources (Whitehead 1989). In contrast, its concentrations have not decreased significantly in populations breeding in remote regions (Pearce et al. 1989) due to the continued environmental cycling of DDT and its atmospheric transport from countries that continue to use these chemicals (Elliott et al. 1989; Government of Canada 1996).

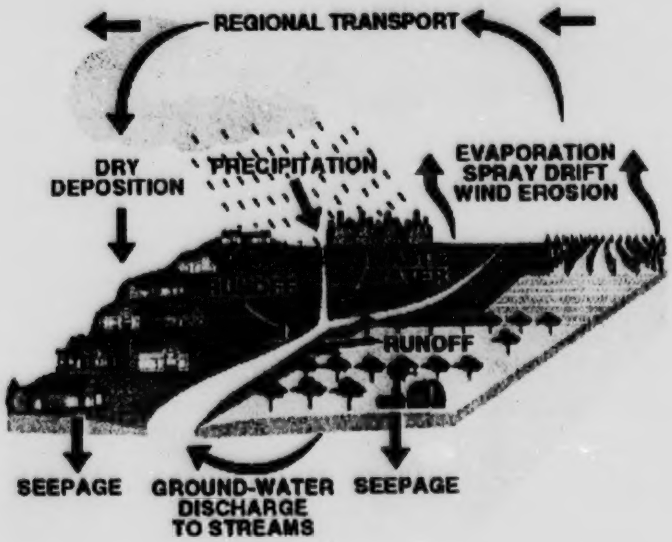

REGIONAL TRANSPORT
DRY DEPOSITION
PRECIPITATION
EVAPORATION
SPRAY DRIFT
WIND EROSION
RUNOFF
SEEPAGE
GROUND-WATER DISCHARGE TO STREAMS
SEEPAGE

Figure 9. Pesticides applied to the terrestrial environment can be transported to the marine environment. Source: (Majewski and Capel 1995).

Pesticides, and organochlorine pesticides in particular, have been detected in marine biota globally:

- hexachlorocyclohexane (HCH) group: α, β, γ-HCH isomers
- DDT group: DDT, DDD, DDE
- cyclodienes: endosulphan, heptachlor, heptachlor epoxide, aldrin/dieldrin/ endrin, chlordane)
- chlorobornanes (toxaphene)
- mirex

For example, HCH has been reported in juvenile harp seals (*Phoca groenlandica*) in the Russian Arctic (0.14 $mg \cdot kg^{-1}$) (Kleivane et al. 1997). High concentrations of β-HCH ($\leq$ 0.67 $mg \cdot kg^{-1}$ (wet wt)) were also measured in ancient murrelet (*Synthliboramphus antiquus*) eggs from the Queen Charlottes Islands, B.C. (Elliott et al. 1989). Total DDT has been detected, for example, in Baltic Sea grey seals (*Halichoerus grypus*) (13 $mg \cdot kg^{-1}$) (Blomkvist et al. 1992). Various cyclodiene pesticides have also been detected in marine mammals globally: chlordane concentrations in Russian Arctic juvenile harp seals were 0.7 mg·kg^{-1} lw (Kleivane et al. 1997); concentrations of chlordane in pilot whales from the Faroe Islands ranged from 1.8 to 4.3 mg·kg^{-1} lw. Sum of toxaphene concentrations in pilot whales (*Globicephala melas*) from the Faroe Islands ranged from 2.0 – 5.0 mg·kg^{-1} lw (Dam and Bloch 2000).

Although many persistent and bioaccumulative pesticides, including DDT, chlordane, and toxaphene, have been largely banned from use in the industrialized world, they are still detected in marine mammals around the world. Chemical residues from soils, where most pesticides were applied, are transported to the marine environment principally via runoff. Developing nations also represent a source of these pesticides as a result of the tendency for organochlorine chemicals to volatilize and move great distances through atmospheric processes.

Table 6. Pesticides that are largely not restricted may be persistent and bioaccumulative, and therefore may present a health-risk to biota. Source: (Tomlin 2000).

Pesticide Name	soil half-life (days)	Vapour Pressure (mPa)	Water Solubility (mg/L)	Kow
Insecticides				
Chlorpyrifos	33-56	3 (25°C)	2 (25°C)	4.70
Dicofol	60-100	negligable at rt	0.8 (25°C)	4.28
Endosulfan	150-240	0.83 (20°C)	0.32 (22°C)	3.13
Esfenvalerate	4-287	0.002 (25°C)	< 0.3 (25°C)	6.22
Fenthion	~2	0.74 (20°C)	4.2 (20°C)	4.84
Fenvalerate	75-80	0.02 (25°C)	< 0.3 (25°C)	6.22
Lindane	60-150	0.05 (20°C)	64 (20°C)	3.00
Permethrin	< 38	0.0015 (20°C)	0.2 (20°C)	6.10
Phorate	7-10	85 (20°C)	50 (25°C)	3.92
Herbicides				
Ethalfluralin	25-46	11 (25°C)	0.3 (20°C)	5.11
Oxadiazon	30-180	0.13 (20°C)	0.7 (20°C)	4.91
Pendimethalin	90-120	4 (25°C)	0.3 (20°C)	5.18
Triallate	56-77	16 (25°C)	4 (25°C)	4.60
Trifluralin	57-126	6.1 (25°C)	<1 (27°C)	5.07
Fungicide				
Quinfozane	120-300	12.7 (20°C)	0.1 (20°C)	4.46
Pentachlorophenol	45	16,000 (100°C)	80 (20°C)	5.12

rt=room temperature

Table 7. The use of many persistent, bioaccumulative, toxic pesticides have been restricted in Canada and the U.S. Source: (Barrie et al. 1992; Li 1999; Voldner and Li 1995).

	Canada	U.S.	Time Period	Global Use (Mt)
Aldrin	voluntarily withdrawn 1990	banned 1989	1950-1992	0.5
Chlordane	registration discontinued 1990	restricted use 1988	1945-1988	0.078
Dieldrin	restricted 1987	banned 1971	1950-1992	0.034
DDT	voluntarily withdrawn 1985	banned 1972	1950-1992	2.6
α-HCH	mixed isomers discontinued 1976	mixed isomers cancelled 1977	1948-1997	10
Toxaphene	withdrawn 1982	banned 1982	1950-1992	1.33

Table 8. The physicochemical properties of a pesticide govern its persistence (soil half-life), transport in the atmosphere (vapour pressure), transport in ocean currents (water solubility), and its bioaccumulation potential (K_{ow}).

Pesticide Name	soil half-life (days)	Vapour Pressure (mPa)	Water Solubility (mg/L)	Kow
Aldrin	10-365	3 (20°C)	0.027 (27°C)	na
Dieldrin	na	0.024-0.4	0.25 (25°C)	3.692-6.2
Chlordane	1460	1.3 (25°C)	0.1 (25°C)	2.78
DDT	730-5500	0.025 (25°C)	< 1 (20°C)	na
HCB	985-2080	1.45 (20°C)	0.05 (25°C)	3.93-6.42
α-HCH	na	0.073 (25°C)	0.12 (20°C)	3.8
γ-HCH (Lindane)	450	5.6 (20°C)	7.3 (25°C)	3.8
Toxaphene	na	0.53-0.67 (25°C)	0.4-3 (25°C)	5.5

Table 9. Regulated pesticides can cause a wide range of toxicological effects in mammals.
Source: (de March et al. 1998)

Pesticide	Reproductive	Developmental	Immunosuppression	Cancer	Adrenal Effects	Thyroid Effect	Porphyria
Aldrin/Dieldrin	√		√	√			
Chlordane	√		√	√			
DDT	√		√		√	√	
HCB	√	√					√
α-HCH			√	√	√	√	
Toxaphene	√		√	√	√	√	

HCB: hexachlorobenzene
DDT: dichlorodiphenyldichloroethane
α-HCH: alpha-hexachlorocyclohexane

4.0 CONTAMINANTS IN COASTAL BRITISH COLUMBIA AND WASHINGTON

4.1 LAND USE IN COASTAL BRITISH COLUMBIA AND WASHINGTON

One regional factor that influences the types and quantities of contaminants entering southern resident killer whale habitat (GPF marine waters) relates to land-use activities adjacent to coastal waters. Urban and agricultural land-use, in particular, affects the type, location, and concentrations of contaminants found in the adjacent coastal marine environment and its biota. Chemicals are discharged directly into coastal waters through wastewaters from municipal and industrial sources and runoff in urban settings. Contaminant emissions from industrial and municipal incinerators into the atmosphere also subsequently contribute to coastal ocean contamination. In both B.C. and Washington, human populations are concentrated along the coast, adjacent to the GPF marine environment (Figure 10). Since considerable amounts of waste are produced in both B.C. and Washington, urban centers will inevitably produce and deliver significant contaminant loads. Pesticide use in agricultural and urban settings also contributes to contamination of the local environment through runoff and atmospheric transport.

4.1.1 South-West British Columbia

The human population of B.C. is concentrated along its south-west coast, within the Georgia Depression. Although this area only accounts for 3 % (18,152,000 ha) of the total land area of B.C. (100,000,000 ha), 67% (2.2 million) of the B.C. population lives here. Most of this population is concentrated within major urban centres, including the following regional districts: Vancouver (population in 2000: 2 011 035), Victoria (334 940) and Nanaimo (134 929). Other non-urban land-use activities such as forestry, agriculture, and transportation/utility corridors, also release contaminants within this region, or influence the movement and fate of contaminants in this region. Since the population of B.C. is predicted to increase significantly (25 %) by the year 2020 (Figure 12), increased contaminant inputs associated with increasing urban land use represents a significant concern for the health of coastal ecosystems.

4.1.2 North-West Washington (Puget Sound Region)

The human population of Washington State is concentrated along its north-west coast, in the Puget Sound Basin (Figure 10). Although the Puget Sound Basin accounts for only 20% (3 522 400 ha) of the total land area in Washington (17 244 600 ha), 70% (3.4 million people) of the population live in this region. Most of this population is concentrated either along the coast of Puget Sound or adjacent to major rivers that discharge into Puget Sound. Major urban areas include several counties: King County, including the City of Seattle and outlying area (population in 2000: 1 685 600), Pierce County, including the City of Tacoma (706 000), Snohomish County, including the City of Everett (593 500), and Whatcom County, including the City of Bellingham (163 500). Industry is concentrated near Commencement Bay, Elliott Bay and the Duwamish Waterway (Seattle). Between 1970 and 1990 the population in the central Puget Sound region increased by 38 percent, with developed land use increasing by 87 percent. With this increased urban land-use, forest cover has concurrently decreased. By studying satellite images, American Forests determined that areas of dense vegetation and tree canopy cover declined by 37% between 1972 and 1996 (Figure 11). Over the same time period, areas with sparce tree and vegetation cover increased by 100% (American Forests 1998). In Washington State, the human population is predicted to increase significantly (22%) by 2020 (Figure 13), with most of this growth concentrated in the Puget Sound basin.

Urban, industrial, and agricultural activities are concentrated in southwestern B.C. and northwestern Washington adjacent to waters frequented by southern resident killer whales. Increasing human populations and their associated urban and agricultural land use are likely to contribute to increased runoff and contaminant inputs into the marine environment over the coming decades.

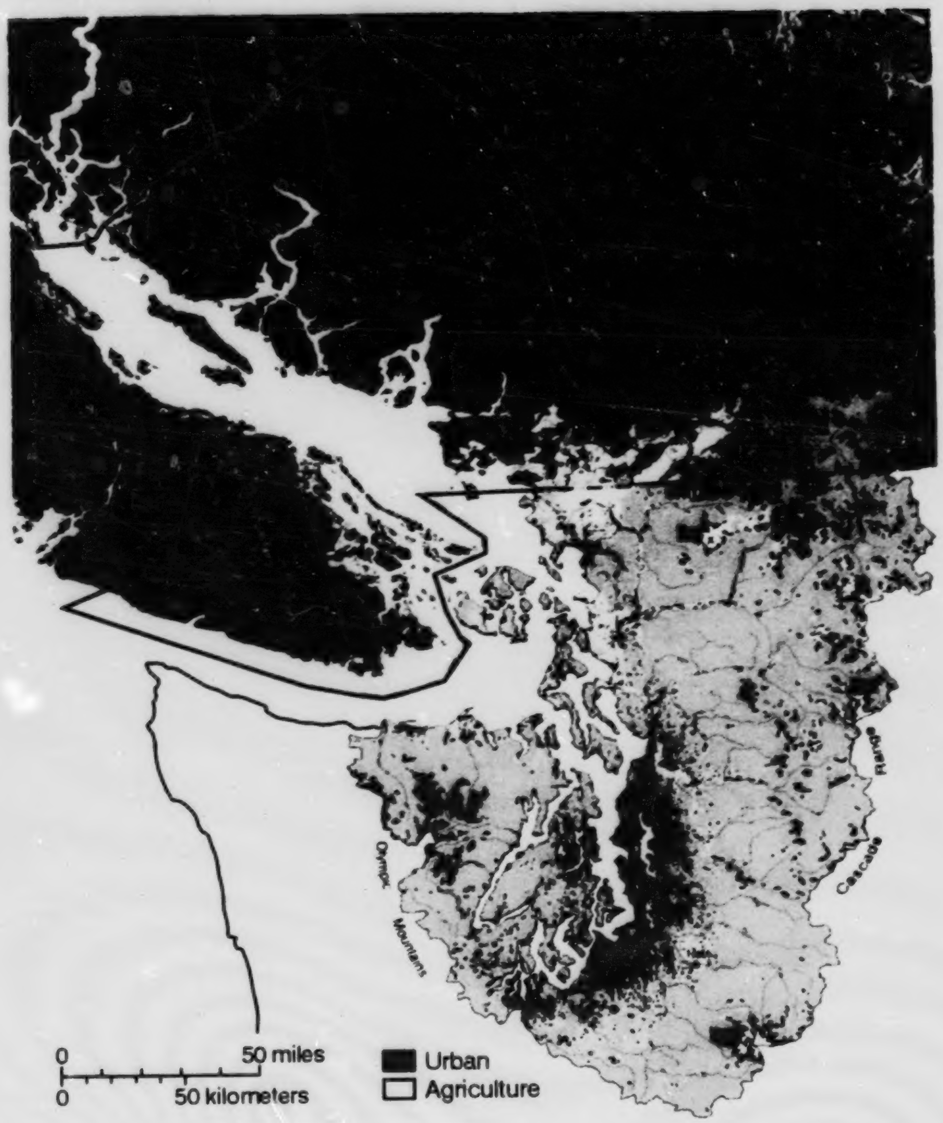
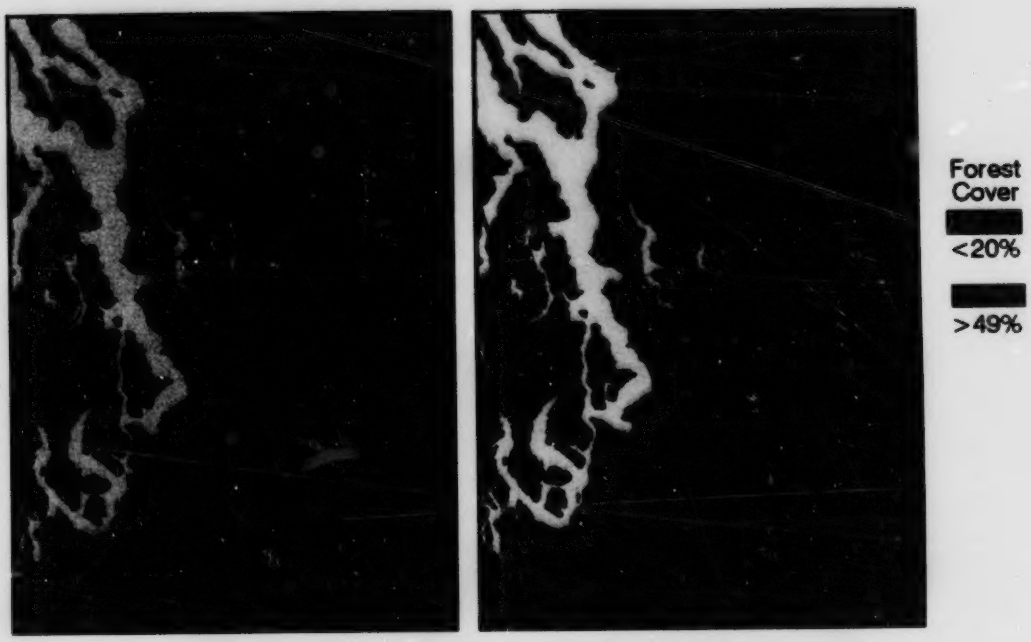

Olympic Mountains
Cascade
Range
0
50 miles
0
50 kilometers
Urban
Agriculture

Figure 10. Urban and agricultural land-use in B.C. and Washington is concentrated in coastal areas adjacent to the waters (the Strait of Georgia and Puget Sound) frequented by southern resident killer whales. Modified from Geographic Data B.C. 2001 and (Staubitz et al. 1997).



1972
1.64 million acres

1996
1.04 million acres

Figure 11. Forest cover in northwest Washington (Puget Sound region) has decreased significantly in recent years as a consequence of urban development, forestry and agricultural land use. Source: (American Forests 1998).

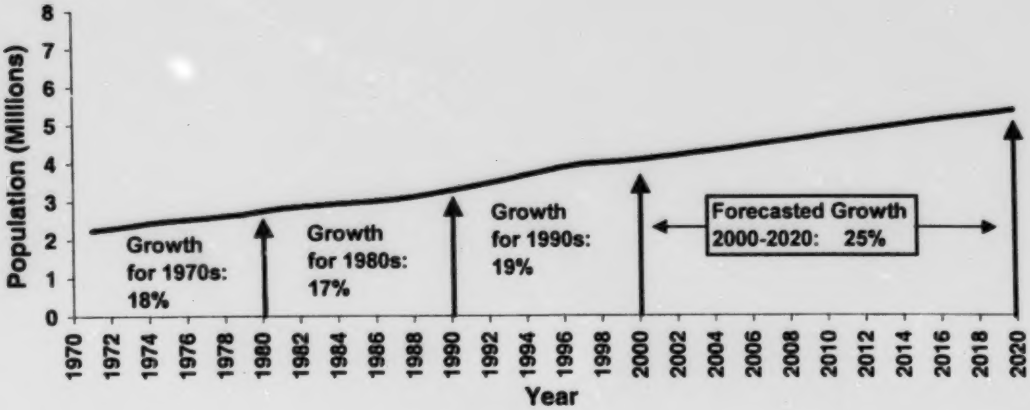


Figure 12. The predicted increase in B.C. human population size is 25% between 2000 and 2020. Source: B.C. Statistics Forecast (May 2000).

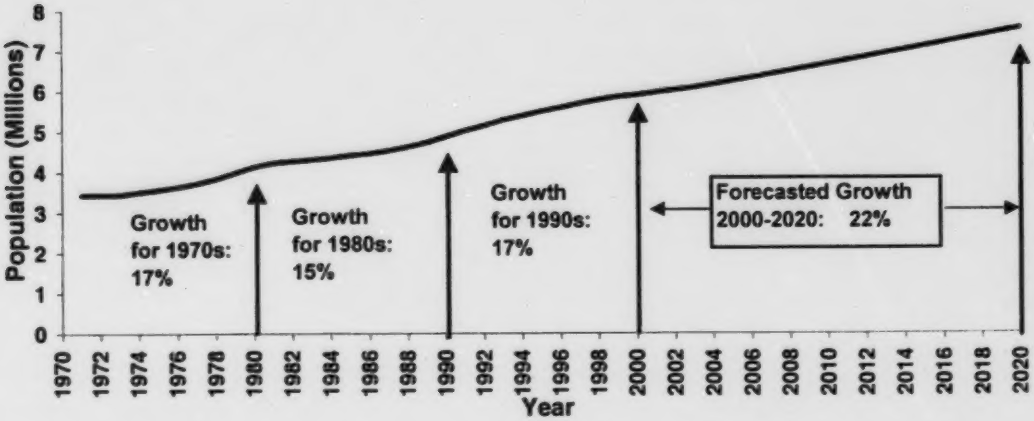


Figure 13. The predicted increase in Washington human population size is 22% between 2000 and 2020. Source: Office of Financial Management Population Forecast (Fall 1997).

4.2 CONTAMINANT TRANSPORT: ATMOSPHERIC AND OCEANIC PROCESSES

4.2.1 Overview

Large scale atmospheric and oceanographic processes contribute to the transport of contaminants from distant sources to the GPF marine environment, and local atmospheric and oceanographic processes can influence local movement, flushing, and retention of contaminants.

4.2.2 Atmospheric Transport

In the North Pacific, major winds are controlled by atmospheric pressure cells (Figure 14). In the winter, southwesterlies dominate wind patterns, prompted by the counterclockwise motion of air around low pressure cells over the Pacific. In the summer, northwesterlies dominate wind patterns, caused by the clockwise movement of air around high pressure cells over the Pacific (Thomson 1981).

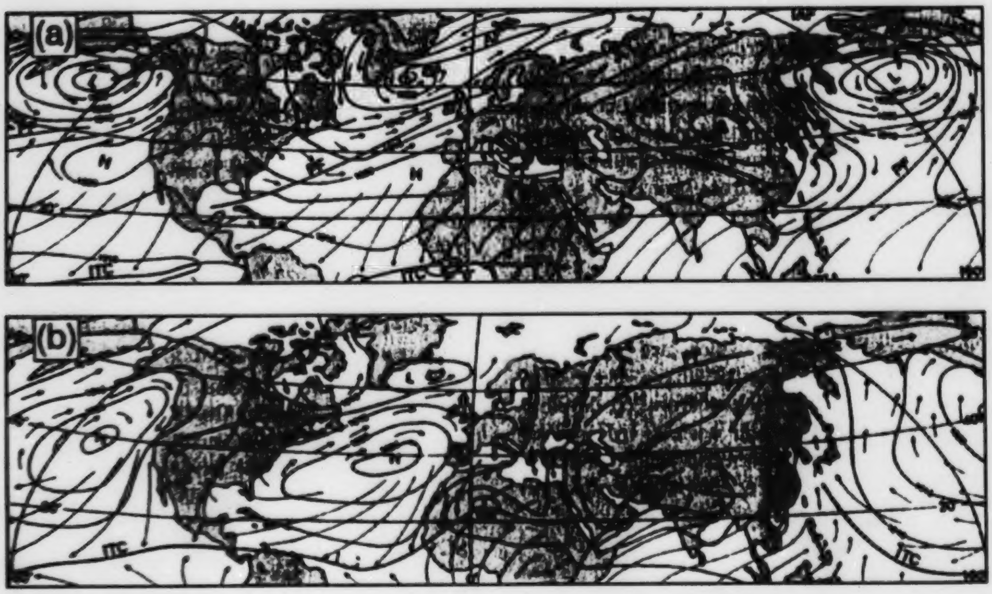


Figure 14. Pressure cells in the North Pacific Ocean cause wind to flow from the a) southwest in the winter and the b) northwest in the summer. Source: (Macdonald et al. 2000a)

Airborne contaminants can be transported long distances in westerly winds from Asia to the North Pacific; this occurs largely in the winter when southwesterly and westerly winds represent the dominant weather systems. The quantity of particulates measured in the Hawaiian Islands in 1981 and 1982 correlated with dust storms in China (Uematsu et al. 1983).

On a local scale, contaminants released in B.C. and Washington through volatilization, incineration, and combustion can be transported and subsequently deposited in local surface waters. During transport, from both distant and local sources, airborne contaminants can enter surface marine waters through dry fallout, wet precipitation, or gas exchange. Contaminants can be deposited directly in surface waters or indirectly through deposition within in a drainage basin, ultimately entering major rivers that discharge into the eastern North Pacific.

4.2.3 Oceanic Transport

4.2.3.1 North Pacific Ocean

In aquatic environments, contaminants bound to particulates (generally water insoluble contaminants) tend to accumulate in sediments close to sources, near sites of atmospheric deposition, and wastewater and river discharges. In contrast, soluble contaminants (e.g. hexachlorocyclohexane (HCH)) can be transported great distances in ocean currents.

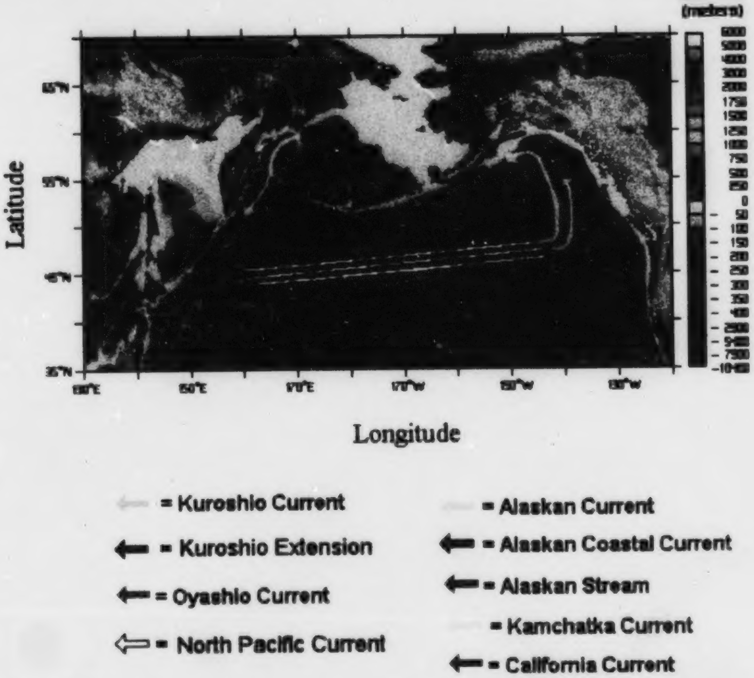

DEPTH
(meters)
Latitude
65°N
55°N
45°N
35°N
130°E
150°E
170°E
170°W
150°W
130°W
Longitude
= Kuroshio Current
= Kuroshio Extension
= Oyashio Current
= North Pacific Current
= Alaskan Current
= Alaskan Coastal Current
= Alaskan Stream
= Kamchatka Current
= California Current

Figure 15. Contaminants from the western Pacific (Asia) may be transported across the Pacific to coastal B.C. and Washington in the North Pacific Gyre. Source: (Reed and Schumacher 1985).

In the North Pacific, upper water moves predominantly in a clockwise gyre (Figure 15) (Pickard and Emery 1990). Water flows from east to west between 8°N and 20°N in the North Equatorial Current. Upon reaching the western North Pacific, most of the water continues north as the Kuroshio Current and subsequently east as the Kuroshio Extension. At 165°E, the Kuroshio Extension is joined by the Oyashio Current to become the North Pacific Current. This current continues eastward until it reaches the west coast of North America between 45°N and 50°N (along the Oregon-Washington-B.C. coasts). At this time, flow is diverted both to the north and south. The northward flow becomes the Alaska Current-Alaskan Stream and southward flow, called the California Current, eventually completes the North Pacific Gyre by moving westward with the North Equatorial Current (Thurman 1989). The length of time it takes for water to move around the entire North Pacific Gyre is estimated at 3-5 years (Macdonald et al. 2000a).

4.2.3.2 Coastal Waters

The Strait of Georgia, Puget Sound, Juan de Fuca Strait (GPF) together form one of the largest estuaries in the world (Table 10; Figures 16 & 17) (Puget Sound Water Quality Action Team 1988). Significant quantities of contaminants enter this marine system indirectly through urban runoff and atmospheric deposition or directly through commercial/industrial/domestic waste discharge and discharges from the major rivers (the Fraser in B.C. and the Skagit in Washington). Whether or not contaminants are flushed from or retained within these basins depends in part on the ocean circulation patterns and the physical structure of the individual basin. Such information is important in understanding the regional sources and fate of contaminants as they relate to killer whales.

In the GPF marine environment, estuarine circulation dominates, with rainfall in the winter and snow melt in the summer driving circulation processes. The upper layer of the water column is largely composed of less dense freshwater, originating from the Fraser River (Strait of Georgia) or Skagit River (Puget Sound) inflows. In the Strait of Georgia, the net flow of water in the surface layer (70-80%) is out of estuary to the ocean, typical of most estuaries. In contrast, the surface layer of water in Puget Sound is largely recirculated and impeded from flowing out to the Pacific Ocean due to the numerous underwater sills in this basin. Although almost all particulate bound contaminants are retained within the Strait of Georgia and Puget Sound Basins (Macdonald and Crecelius 1994; Staubitz et al. 1997), dissolved contaminants are more effectively flushed from the Strait of Georgia compared to Puget Sound.

The bottom layer of the estuarine water column is comprised of ocean water that has submerged below the less dense surface layer; the net flow of this deeper layer is out of the Pacific Ocean, through Juan de Fuca Strait, and into either the Strait of Georgia or Puget Sound. Movement of this ocean water layer into the estuaries is influenced by tides; at high tide ocean water enters the estuarine system and at low tide ocean water leaves this system. At the boundary of the freshwater surface layer and the deeper marine layer, considerable mixing occurs, forming a brackish (intermediate salinity/density) layer that generally moves together with the surface layer, out of Juan de Fuca Strait and into the Pacific Ocean.

Table 10. Flushing or retention of contaminants in the Strait of Georgia, Puget Sound and Juan de Fuca Strait are heavily influenced by the physical properties of these basins. Source: (Macdonald and Crecelius 1994).

	Strait of Georgia	**Puget Sound**	**Juan de Fuca Strait**
Type of Estuary	Partially-mixed	Partially-mixed	Well-mixed
Area (km^2)	6,800	2,300	3,700
Volume (km^3)	1,050	169	402
Mean depth (m)	155	62	200
Maximum depth (m)	420 Texada Is.	284 Pt. Jefferson	300+ (at mouth)
Yearly Mean Runoff (m^3•s^{-1})	5,800	2,200	500
Drainage Area (km^2)	286,890	40,327	7,420
Sill Depths (m)	90 (HS); 50 (RS)	65; 105 (AI)	130
Basin Flushing time, summer	50-75 days	120-140 days	30-60 days
Basin Flushing time, winter	100-200 days	120-140 days	30-60 days
Transport (x10^6 m^3/s)	variable/ill-defined	0.01-0.10	0.10-0.90

HS=Haro Strait; RS=Rosario Strait; AI=Admiralty Inlet; V-GP=Victoria-Green Point

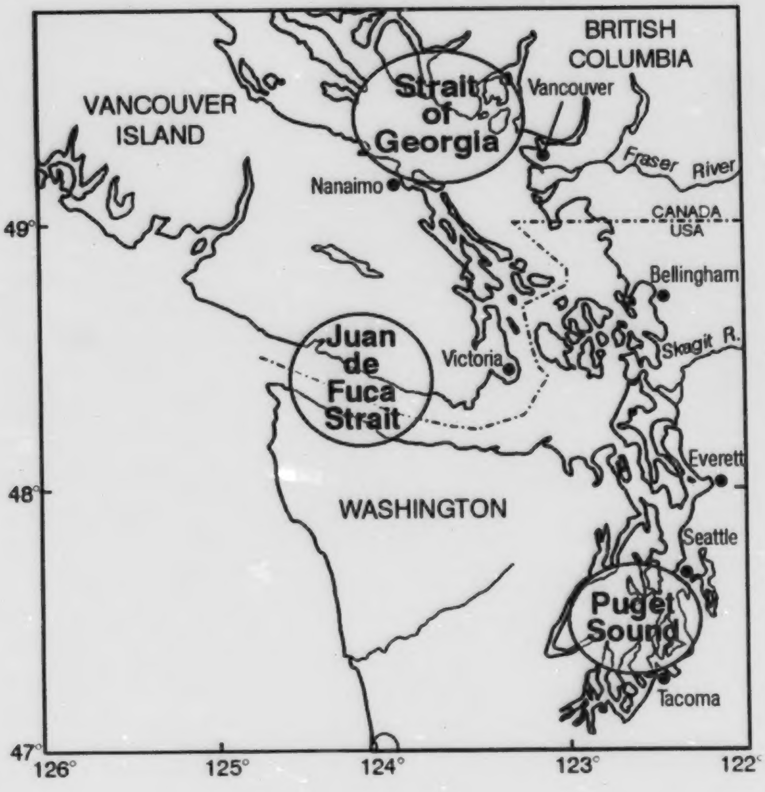

BRITISH
COLUMBIA
VANCOUVER
ISLAND
Strait
of
Georgia
Vancouver
Fraser River
Nanaimo
CANADA
USA
49°
Bellingham
Juan
de
Fuca
Strait
Victoria
Skagit R.
Everett
48°
WASHINGTON
Seattle
Puget
Sound
Tacoma
47°
126°
125°
124°
123°
122°

Figure 16. The Strait of Georgia, Juan de Fuca Strait and Puget Sound are the principal coastal bodies of waters frequented by southern resident killer whales.

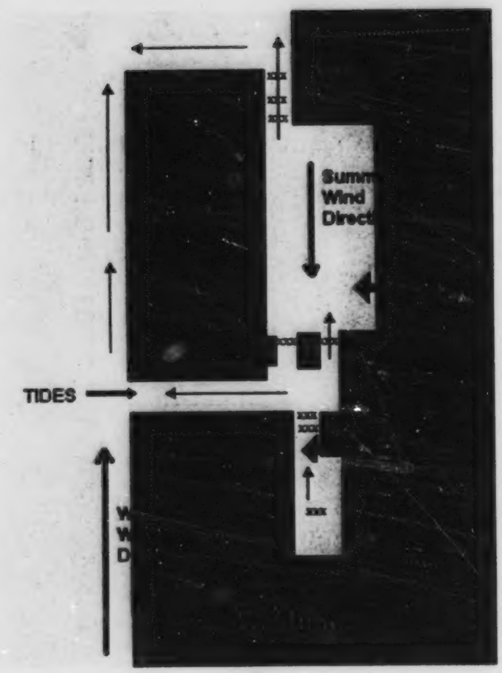

xxx
xxx
xxx
Summ
Wind
Direct
TIDES
xxx
xxx
xxx
W
W
D

Figure 17. Marine water enters the Strait of Georgia-Puget Sound-Juan de Fuca Strait estuary during high tide. This inflowing marine water (tides) submerges under a less dense freshwater layer originating from the Fraser and Skagit rivers. Although water may be trapped, particularly in Puget Sound due to the presence of major sills (xxx), the net movement of shallow waters (⟶) is out of this large estuarine system. Source: (Thomson 1994).

4.3 CONTAMINANTS IN SEDIMENTS

Sediments have been routinely monitored in B.C. and Washington because they can represent an important "source" of contaminants to the marine food web. Sediment concentrations of many contaminants (PCBs, DDT, metals, etc.) can be high as a result of their potential for adsorbtion to particulates and subsequent settling to the ocean bottom. Since sediments accumulate contaminants over time they can be used to estimate the combined ("integrated") contaminant inputs from point and non-point sources. In order to minimize contaminant risk to marine life, local contaminant "hotspots" can be identified, appropriate source controls can be implemented, and in certain circumstances, sediment clean up operations may be considered (dredging, removal, and/or capping).

Sediment cores taken from the Strait of Georgia, Juan de Fuca Strait and Puget Sound reflect temporal contaminant trends as a result of continuous sedimentation and burial. Such cores can provide an overview of contaminants from periods prior to anthropogenic production (1850s-1900s) to more recent times (1940-present) (Macdonald and Crecelius 1994). Contaminant concentrations in sediment cores largely mirror their use (and regulation) by society, although the presence of some dioxins and furans, PAHs, and metals prior to industrialization reflects natural sources of these compounds (Macdonald and Crecelius 1994). Despite regulation, many of these chemicals continue to be found in surface sediments above background levels because they are released at low levels from various sources or are transported atmospherically from regions where they persist or continue to be used (Macdonald and Crecelius 1994).

4.3.1 Contaminated Sediments in British Columbia

In B.C., "hotspots" for sediment contamination include the following areas: *Victoria and Esquimalt Harbours; Fraser River Estuary; Burrard Inlet (Vancouver Harbour),* (Brewer et al. 1998; Emmett et al. 1996; Environment Canada et al. 1998; Foy et al. 1995)(Figures 18 & 19; Table 11).

In B.C., the Fraser River Action Plan (FRAP), Fraser River Estuary Management Program (FREMP), the Burrard Inlet Environmental Action Program (BIEAP), and the Victoria and Esquimalt Harbours Environmental Action Program (VEHEAP) have been set up to address various environmental concerns, including contaminated sediments. These programs are involved in source control measures and the clean-up of contaminated sediments. British Columbia has also joined an Environmental Cooperation Agreement with Washington State to coordinate environmental protection efforts in the Georgia Basin and Puget Sound.

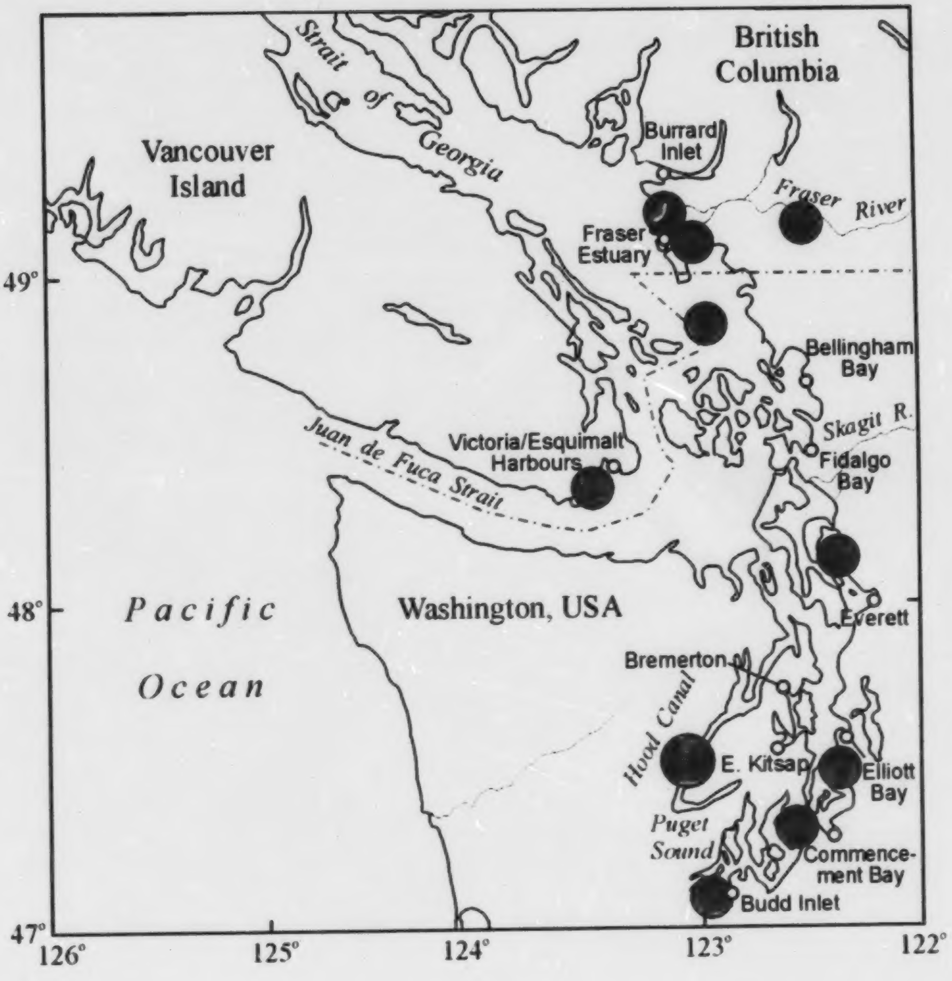
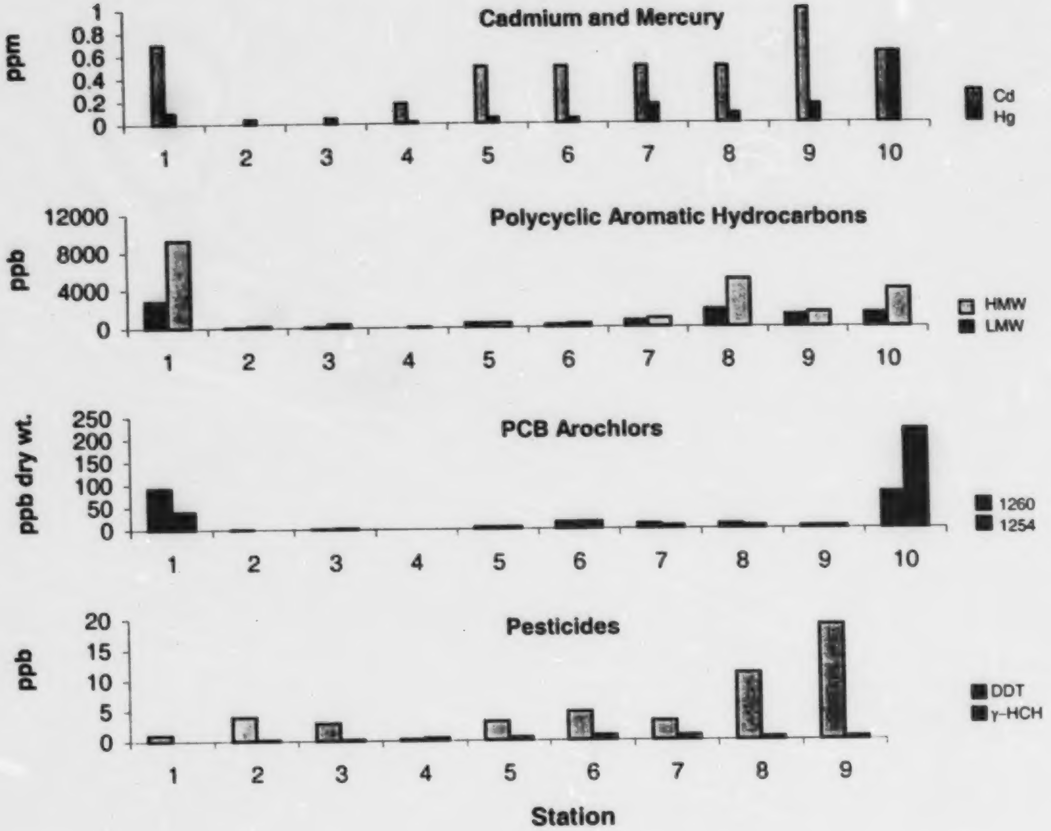

British Columbia
Strait of Georgia
Vancouver Island
Burrard Inlet
Fraser River
Fraser Estuary
Bellingham Bay
Skagit R.
Fidalgo Bay
Victoria/Esquimalt Harbours
Juan de Fuca Strait
Pacific Ocean
Washington, USA
Everett
Bremerton
Hood Canal
E. Kitsap
Elliott Bay
Puget Sound
Commencement Bay
Budd Inlet
49°
48°
47°
126°
125°
124°
123°
122°

Figure 18. Contaminated sediments are concentrated in areas near large B.C. and Washington urban centers. Numbers (1-10) represent sampling stations; concentrations of metals, PAHs, PCBs, and DDT that correspond to station numbers are presented in Figure 19.



HMW-high molecular weight polycyclic aromatic hydrocarbons; LMW-low molecular weight polycyclic aromatic hydrocarbons; γ-HCH-gamma hexachlorocylcohexane

Figure. 19. Concentrations of metals, PAHs, PCBs, and DDT are concentrated in harbours and near large urban centres in B.C. and Washington. Concentrations of metals, PCBs and DDT are particularly high in Puget Sound (station 6-10). Station **1**: Victoria/Esquimalt Harbours (Foy et al. 1995); stations **2**, **3**, and **4**: Fraser River (Brewer et al. 1998); station **5**: Strait of Georgia; stations **6** to **10**: Puget Sound (Department of Ecology, 1995).

Table 11. Sites of sediment contamination in the Strait of Georgia are concentrated near municipal and industrial sources. Source: (Brewer et al. 1998; Emmett et al. 1996; Environment Canada et al. 1998; Foy et al. 1995).

	Sources	Contaminants
Fraser River Estuary	pulp mills	metals
	lumber industry	PAHs
	municipal WWTPs	PCBs
Burrard Inlet (Vancouver Harbour)	combined sewer outfalls	metals
	oil refineries	PAHs
	pulp mills	PCBs
	Lions Gate WWTP	
Victoria-Esquimalt Harbour	stormwater discharges	metals
	B.C. Hydro	PAHs
	shipyard	PCBs (a few sites)

WWTP = wastewater treatment plant

4.3.2 Contaminated Sediments in Washington

In Puget Sound, 38% (2 300 ha) of the total sediment area surveyed by the Washington Department of Ecology (over 6 100 ha) exceeded State sediment quality standards. Sites of particular concern are located in the following areas: *Bellingham Bay; Fidalgo Bay; Everett Harbour, Port Gardner; Bremerton and Eastern Kitsap Peninsula Inlets (Eagle Harbour, Sinclair Inlet, Liberty Bay, Dyes Inlet, Clam Bay); Elliott Bay; Commencement Bay; Budd Inlet* (Washington State Department of Ecology 2000) (Figures 18 & 19; Table 12). Major sources of contaminants to Puget Sound consist of urban and industrial activities (Figure 20).

Table 12. Sediments in Puget Sound that are contaminated are found near municipal and industrial sources. Source: (Norton 2000; URS Greiner Inc. for Engineering Field Activity Northwest 1996; URS Greiner Inc. for Engineering Field Activity Northwest 1999; Washington State Department of Ecology 2000).

	No. of Contaminated Sediment Sites	Sources	Contaminants	Cleanup Stages
Bellingham Bay	9	historic landfill shipyard chlor-alkalki plant pulp and paper mill	metals: Hg	early
Fidalgo Bay	6	shipyards oil and other spills industrial	PAHs	early
Everett Harbor Port Gardner	9	pulp and paper mills industrial	PAHs and metals (Hg) one site: PCBs	pulp mill sites cleaned up other sites not started
Bremerton and Eastern Kitsap	11	wood treatment facility naval operations harbours	Sinclair and Dyes: PCBs all sites: Hg, Cu, Pb, PAHs	later
Elliott Bay	19	stormwater shipyard	PAHs PCBs Hg	clean up underway
Commencement Bay	12	stormwater shipyard	PAHs PCBs Hg	later
Budd Inlet	2	wood treatment facility sewers: industrial and municipal	Cd dioxins pentachlorophenol PAH; tributyltin	feasibility study underway

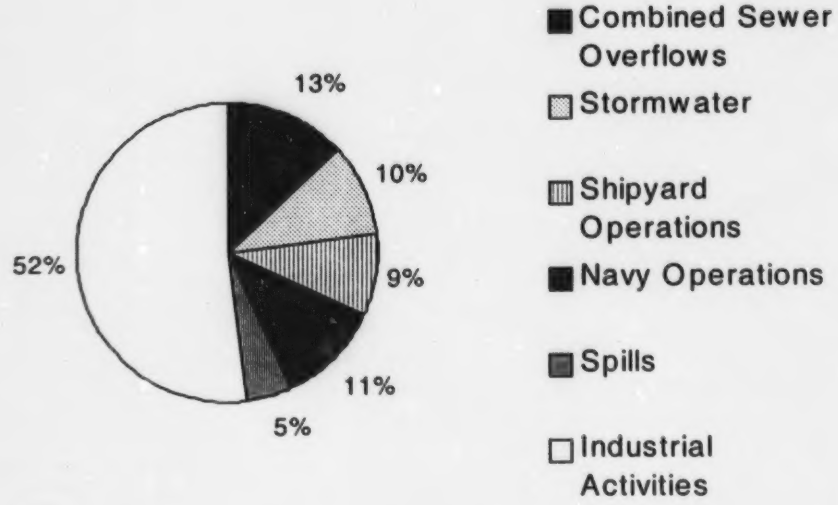


Figure 20. Industrial and urban activities are the major sources of contaminants to sediments in Washington. Source: (Washington State Department of Ecology 2000).

In 1991, Washington's Department of Ecology developed the Sediment Management Standard Program (Washington State Department of Ecology 2000). This program manages the cleanup and source control measures at contaminated sediment sites, and is also involved in the development of sediment quality standards. Washington is currently the only state in the U.S. that has established sediment quality guidelines. Legislation that regulates cleanup includes Washington's *Model Toxics Control Act* or the *U.S. Comprehensive Environmental Response Compensation Liability Act* (Superfund). Cleanup can be impeded by various factors including the lack of adequate contaminated sediment disposal sites, lack of cooperation with the liable parties, lack of appropriate source control, and overall funding limitations (the estimated cost to clean up all these sites in Puget Sound is between U.S. $241 million to $1.1 billion) (Washington State Department of Ecology 2000).

Although recent regulatory actions have greatly restricted the release and introduction of certain chemicals into coastal B.C. and Washington, contaminant levels at many sediment sites exceed guidelines. These sites may contaminate food chains near urban and industrial centres and present a local or regional risk to biota. B.C. and Washington have independent, as well as joint (transboundary), programs to address the issue of sediment contamination as it relates to source control measures and clean-up strategies.

4.4 CONTAMINANTS IN WILDLIFE

Although generally they may not be directly exposed to sediment-bound contaminants, marine mammals and fish-eating birds may be indirectly exposed to contaminants of sedimentary origin. Through remobilization, contaminants in the sediments can move through the food web from lower trophic level organisms that inhabit the ocean bottom to high trophic level organisms.

4.4.1 Contaminants in Marine Mammals

Very high concentrations of PCBs have been recently measured in killer whales frequenting the GPF environment. Concentrations of these chemicals are particularly high in southern residents that frequent Puget Sound and the Strait of Georgia (males: 146.3 ± 32.7 $mg \cdot kg^{-1}$ lw (*n*=4); females 55.4 ± 19.3 $mg \cdot kg^{-1}$ lw (*n*=2)) compared to northern residents that frequent the coastal waters of northern Vancouver Island and northern B.C. (males: 37.4 ± 6.1 $mg \cdot kg^{-1}$ lw (*n*=8); females 9.3 ± 2.8 $mg \cdot kg^{-1}$ lw (*n*=9)) (Figures 1 and 21) (Ross et al. 2000). These concentrations exceed levels shown to cause toxic effects in harbour seals, including immune and endocrine disruption (Ross et al. 1996a; Ross et al. 2000) suggesting that killer whales may be at risk for adverse health effects. Similar to other marine mammals, female killer whales were generally less contaminated than males, since females transfer part of their contaminant burden to their offspring during lactation (Addison and Brodie 1977; Ross et al. 2000). The PCB composition measured in killer whales was dominated by highly chlorinated congeners (e.g. PCB 153 and 138), which are resistant to metabolic breakdown and excretion (Ross et al. 2000).

Polychlorinated biphenyls and dioxins and furans have also been measured in free-ranging harbour seal (*Phoca vitulina*) pups in the Strait of Georgia and southern Puget Sound (Calambokidis et al. 2001; Simms et al. 2000). Concentrations of PCBs were significantly greater in pups in Puget Sound (15.4 ± 2.2 $mg \cdot kg^{-1}$ lw) than in B.C. (2.3 ± 0.2 $mg \cdot kg^{-1}$ lw) (Figure 21). Concentrations of dioxins and furans were greater in B.C. (Σ dioxins: 343.9 ± 24.7 $ng \cdot kg^{-1}$ lw; Σ furans: 47.9 ± 25.3 $ng \cdot kg^{-1}$ lw) than in Puget Sound seals (Σ dioxins: 149.6 ± 21.1 $ng \cdot kg^{-1}$ lw; Σ furans: 12.2 ± 1.6 $ng \cdot kg^{-1}$ lw), probably reflecting the extensive history (now regulated) of pulp mill and forestry-related contamination of the Strait of Georgia (Ross et al. 2002; Simms et al. 2000). In addition to the effects listed in the previous paragraph, dioxins and furans can disrupt retinal levels (Vitamin A), a micronutrient required for normal growth and development (Simms and Ross 2001).

Higher concentrations of PCBs in southern resident killer whales and harbour seals occupying southern Puget Sound suggest that the food web in southern Puget Sound is significantly more contaminated than the food web in northern B.C. coastal waters. A combination of factors likely contributes to the contamination of Puget Sound, including greater contaminant inputs into Puget Sound from industrial and domestic activities, and decreased flushing and sedimentation rates in Puget Sound compared to the Strait of Georgia (Cullon et al. 2001; O'Neill et al. 1998; West et al. 2001a).

Detectable concentrations of POPs (PCBs, *p,p'*-DDE, and heptachlor epoxide) have also been reported for other mammals including wild mink (*Mustela vison*) and river otters (*Lutra canadensis*) of the lower Fraser, Kootenay, and Columbia Rivers (Elliott et al. 1999; Harding et al. 1999). Although PCB concentrations in otter livers have declined 10 fold between 1980 and 1990, concentrations measured in otter livers (1500 $\mu g \cdot kg^{-1}$) collected from the lower Columbia River remain sufficiently high to cause reproductive impairment (Elliott et al. 1999).

4.4.2 Contaminants in Birds

In addition to aquatic mammals, high concentrations of a variety of contaminants (e.g. PCBs, dioxins, heavy metals, and DDT) have also been detected in fish-eating birds including bald eagles (*Haliaeetus leucocephalus*), red tailed hawks (*Buteo jamaicensis*), ospreys (*Pandion haliaetus*), Leaches storm-petrels (*Oceanodroma leucorhoa*), rhinoceros auklets (*Cerorhinca monocerata*), Cassin's auklets (*Ptychoramphus aleuticus*), ancient murrelets (*Synthliboramphus antiquus*) and fork tailed storm petrels (*Oceanodroma furcata*) along the North American Pacific Coast (Elliott et al. 2000; Elliott and Norstrom 1998; Elliott et al. 1996a; Elliott and Scheuhammer 1997; Elliott et al. 1996b). Contaminant concentrations are particularly high in birds occupying habitat close to industrial activity.

High contaminant concentrations have been measured in bald eagle nestlings inhabiting the Strait of Georgia near Powell River (PCB: 56 $\mu g \cdot kg^{-1}$ (n=10); DDE: 20.2 $\mu g \cdot kg^{-1}$ (n=10)) (Elliott and Norstrom 1998). In osprey eggs, concentrations of PCBs and certain organochlorine pesticides measured were greater in the more industrialized Columbia River basin than in the Fraser River basin (Elliott et al. 2000). Elevated concentrations of dioxins and furans have been reported in bird species sampled near pulp and paper mills. Concentrations of dioxins and furans in bald eagle nestlings' plasma were greater (2,3,7,8-TCDD: 0.37 $ng \cdot kg^{-1}$ (n=10)) at pulp and paper sites (e.g. Powel River) (Elliott and Norstrom 1998) than concentrations at reference sites (e.g. Johnstone Strait: 2,3,7,8-TCDD: 0.03 $ng \cdot kg^{-1}$ (n=4)). In osprey eggs downstream of pulp and paper mills, concentrations of dioxins and furans were also greater (e.g. Kamloops (1997): 2,3,7,8-TCDD: 1.4 $ng \cdot kg^{-1}$ (n=5)) than at upstream sites (e.g. Kamloops: 2,3,7,8-TCDD: 0.6 $ng \cdot kg^{-1}$ (n=5)) (Elliott et al. 2000).

Concentrations of chemicals that were regulated in the 1970s (DDE, PCBs, dieldrin, heptachlor epoxide) have subsequently declined in Strait of Georgia birds, particularly near contaminant point sources. For example, after their regulation, concentrations of these chemicals declined in great blue herons (*Ardea herodias*) (Whitehead 1989) and seabird eggs (Elliott et al. 1989). Dioxin and furan concentrations in pelagic cormorants in the Strait of Georgia also declined significantly (by 99%) since 1988 as a consequence of regulation of these chemicals in pulp and paper mill processes (Canadian Wildlife Service, Environment Canada, Ottawa, Canada). Although PCB concentrations in pelagic cormorants also declined significantly (by 68-78%) since the 1970s, they have stabilized in recent years (Figure 22). This may be attributed to the continued cycling of PCBs in the environment, their release from sites where they either continue to be used or are stored or disposed of, and through atmospheric transport (Canadian Wildlife Service, Environment Canada, Ottawa, Canada). Similarly, in birds occupying more pristine sites, far from pollutant point sources, concentrations of certain chemicals (DDE and PCBs) have remained relatively constant since the late 1960s (Pearce et al. 1989).

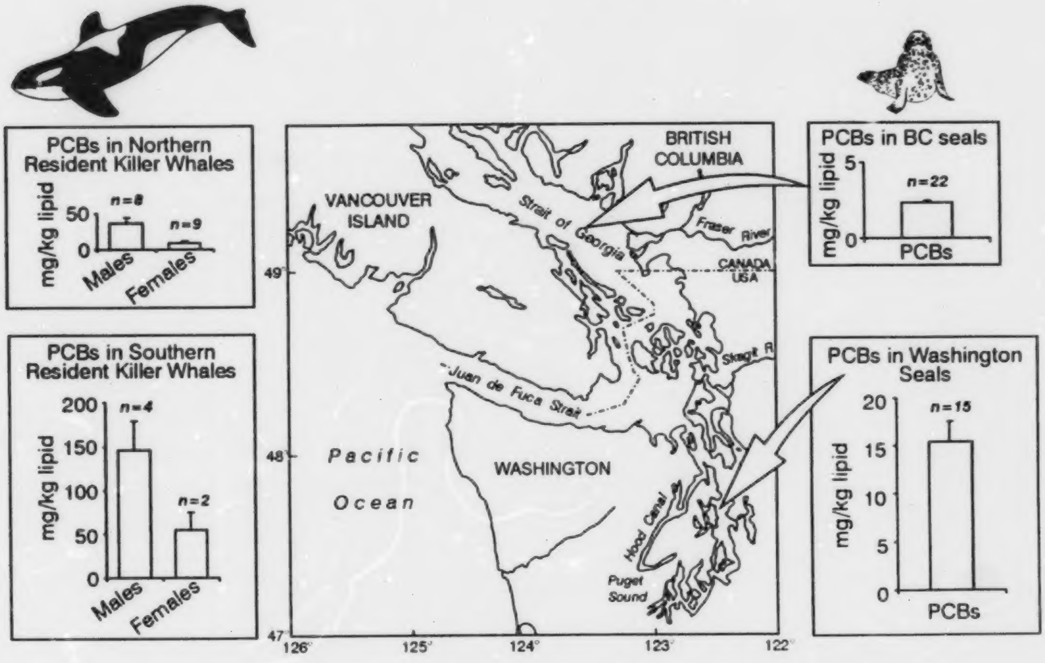

PCBs in Northern Resident Killer Whales
mg/kg lipid
50
0
n=8
n=9
Males
Females
PCBs in Southern Resident Killer Whales
mg/kg lipid
200
150
100
50
0
n=4
n=2
Males
Females
BRITISH COLUMBIA
VANCOUVER ISLAND
Strait of Georgia
Fraser River
CANADA
USA
Skagit R
Juan de Fuca Strait
Pacific Ocean
WASHINGTON
Hood Canal
Puget Sound
49°
48°
47°
126°
125°
124°
123°
122°
PCBs in BC seals
mg/kg lipid
5
0
n=22
PCBs
PCBs in Washington Seals
mg/kg lipid
20
15
10
5
0
n=15
PCBs

Figure 21. Regional PCB "hotspots" contribute to the contamination of marine mammals. Despite similar dietary preferences, PCB concentrations are significantly higher in southern resident killer whales than northern resident killer whales. PCB concentrations are also higher in resident harbour seals in Puget Sound than seals in the Strait of Georgia. Source: (Ross et al. 2002; Simms et al. 2000).

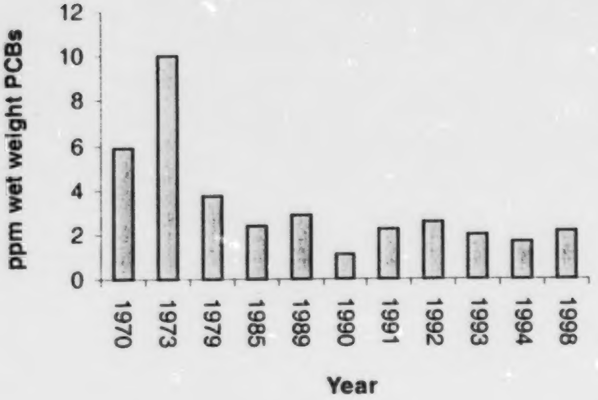


Figure 22. Although PCB concentrations in double crested cormorant eggs declined significantly shortly after their regulation in the 1970s, concentrations of this chemical class have since stabilized. Source: (Canadian Wildlife Service, Environment Canada, Pacific and Yukon Region).

Contaminant profiles in southern resident killer whales and harbour seals suggest that the Puget Sound food web is significantly more contaminated than the Strait of Georgia and northern B.C. food web. This reflects, in part, greater historical contaminant inputs to Puget Sound from industrial and domestic activities and lower flushing and sedimentation rates of Puget Sound compared to the Strait of Georgia. In the Strait of Georgia, concentrations of various contaminants in different mammal and seabird species may be elevated near local industries (e.g. pulp and paper mills), although regulations have helped to reduce inputs into this basin.

5.0 CONTAMINANT POINT SOURCES IN BRITISH COLUMBIA AND WASHINGTON

5.1 OVERVIEW

Point source pollution includes all pollution that originates from an identifiable source that is discharged through pipes to the environment. This type of pollution is generally easier to regulate than non-point source pollution since the source can be readily identified.

In B.C., point source discharges of wastewater to the marine environment are regulated under the provincial *Waste Management Act* and the *Canadian Fisheries Act*. Industry regulations (e.g. Pulp and Paper Effluent Regulations; Metal Mining Effluent Regulations) provide national baseline standards. In several locations, including Burrard Inlet and Boundary Bay, voluntary water quality objectives are being developed at the provincial level (British Columbia Ministry of Environment Lands and Parks and Environment Canada 1993).

In Washington, point source discharges of wastewater to the marine environment are regulated under the Federal *Clean Water Act* (1972); all sources that discharge wastewater require a National Pollutant Discharge Elimination System (NPDES) permit. The Washington State Department of Ecology is the principal enforcement agency of the NPDES program and also provides pollution control laws and regulation.

In B.C. and Washington, pulp and paper mills, mines, oil refineries, oil spills (Figure 23), combined sewer systems and sewage treatment plants (Figure 24), all represent point sources of pollution to the coastal environment.

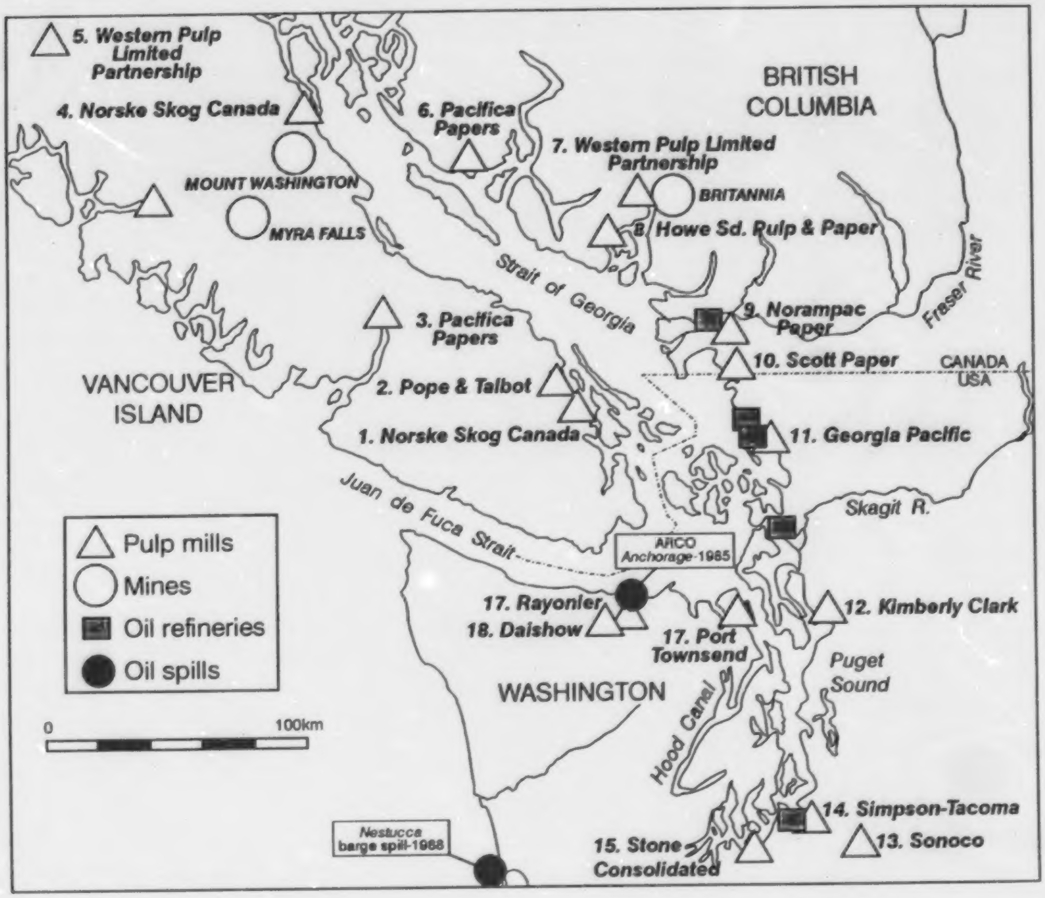

5. Western Pulp Limited Partnership
4. Norske Skog Canada
MOUNT WASHINGTON
MYRA FALLS
6. Pacifica Papers
7. Western Pulp Limited Partnership
BRITANNIA
BRITISH COLUMBIA
8. Howe Sd. Pulp & Paper
Strait of Georgia
Fraser River
9. Norampac Paper
3. Pacifica Papers
10. Scott Paper
CANADA
USA
VANCOUVER ISLAND
2. Pope & Talbot
1. Norske Skog Canada
11. Georgia Pacific
Juan de Fuca Strait
Skagit R.
ARCO Anchorage-1985
Pulp mills
Mines
Oil refineries
Oil spills
17. Rayonier
18. Daishow
17. Port Townsend
12. Kimberly Clark
Puget Sound
WASHINGTON
0
100km
Hood Canal
14. Simpson-Tacoma
Nestucca barge spill-1988
15. Stone Consolidated
13. Sonoco

Figure 23. Pulp and paper mills, mines, oil refineries and oil spills discharge contaminants directly into the Strait of Georgia-Puget Sound-Juan de Fuca Strait marine waters occupied by southern resident killer whales.

5.2 MUNICIPAL WASTEWATER

5.2.1 Wastewater Collection

Municipal wastewater can contain domestic, industrial, and commercial wastes, and depending on the system, stormwater runoff. These sources contribute hundreds of different classes of toxic chemicals to the sewer system (People for Puget Sound and Georgia Strait Alliance 1995). These chemicals include metals (Cd, Hg, Cu, Pb), synthetic organic chemicals (PCBs, dioxins/furans, pesticides), chlorine, solvents, oils, bleaches, and nonylphenols (found in detergents, soaps, and shampoos). Three types of sewer systems -- combined, sanitary and storm -- can be used to transport wastewater to the wastewater treatment plant.

In older sewage systems, one pipe combines sewage, stormwater, and urban runoff from roads, rooftops, yards, golf courses and parking lots for transport to a sewage treatment facility (combined sewers). However, this system can be overwhelmed during intense rain events with the excess volume discharging directly (untreated) into the receiving environment via outfalls called combined sewer overflows (CSOs). As a consequence, overflow events introduce contaminants directly from industrial/domestic sources and urban runoff into the aquatic environment. Chemicals in runoff include oil, grease, hydrocarbons and pesticides. In B.C.'s lower mainland, an area that includes the City of Vancouver, there are 52 CSO discharge sites (32 miilion cubic meters discharged per year) (Greater Vancouver Regional District 1999a; Lee 1998). In the Puget Sound region, an area that includes the city of Seattle, there are 140 CSO discharge sites (10.6 million cubic meters discharged per year); of these, 91 CSO sites are located in Seattle (7.6 million cubic meters discharged per year) (Staubitz et al. 1997).

In newer sewage systems, separate pipes collect sewage (sanitary sewers) from either urban or stormwater runoff (storm sewers). Although such separate pipe systems prevent discharge of the entire sewage/runoff directly to the aquatic environment during storm events, urban runoff may be discharged directly to the receiving environment without treatment. This results in the release of heavy metals, pesticides and PAHs that are rinsed off urban surfaces into the aquatic environment.

In all sewer systems, overflows and bypasses are constructed to divert raw sewage directly into the aquatic environment when the facility is overloaded, or during mechanical failures and repair operations. Although overflows and bypasses prevent raw sewage from backing up onto city streets, untreated sewage and its contaminant loads are still released directly to the aquatic environment upon occasion.

5.2.2 Wastewater Treatment

In general, wastewater from sewer systems (except storm sewers) is treated at wastewater treatment plants (WWTP) at primary, secondary, or tertiary levels before being discharged into the environment. B.C. discharges 3 million cubic meters of effluent from WWTPs into the Fraser River and the Straits of Georgia and Juan de Fuca every day (People for Puget Sound and Georgia Strait Alliance 1995). Washington discharges 3.4 million cubic meters of effluent into Puget Sound and Juan de Fuca Strait every day (People for Puget Sound and Georgia Strait Alliance 1995). See Figure 24 for major sewage discharges in B.C. and Washington.

Sewage treatment processes reduce total suspended solids, biological oxygen demand, fecal coliform bacteria, pH, oil and grease in wastewater. Only more recently, however, have toxic pollutants been targeted in sewage treatment processes in B.C. and Washington (People for Puget Sound and Georgia Strait Alliance 1995). The following general processes are used in sewage treatment facilities to reduce conventional and toxic pollutants in wastewater (People for Puget Sound and Georgia Strait Alliance 1995):

1) *Primary treatment* involves the separation of wastewater by settling processes into three phases: sinking solids (sludge), liquid effluent, and floating solids (oil, grease). The sludge and floating components are removed from the final effluent. Approximately 40-50% of total suspended solids, 50% of the metals, and a small proportion of organic contaminants are removed from effluent by this process.

2) *Secondary treatment (biological treatment)* involves supplying oxygen to the wastewater to assist in the aerobic breakdown of organic material by microorganisms. This process minimizes anaerobic breakdown of wastewater and the associated release of toxic chemical by-products (e.g. methane, hydrogen sulphide and ammonia). This process removes 85-95% of the suspended solids, 75% of the metals and 70-80% of the organic contaminants from effluent.

3) *Tertiary treatment* involves the removal of nutrients and in some cases organic contaminants through alum addition, the use of activated carbon, chemical oxidation, ion exchange, ultra-filtration, reverse osmosis, and/or electrodialysis.

Higher treatment levels produce more solid waste (sludge) that contains more toxic contamination than primary or secondary treatment sludge. Sludge can contain a range of toxic contaminants including PCBs, dioxins, PAHs, heavy metals (Cd, Hg, Pb), and chlorinated pesticides (DDT, dieldrin, aldrin, endrin, chlordane, heptachlor, lindane, 2,4-D, 2,4,5-T). These contaminants can be released into the aquatic environment depending on the sludge disposal methods that include landfill and incineration (Sierra Legal Defence Fund Report 1999). More recently, sludge has been applied to soil as a conditioner and fertilizer. 70 000 tonnes of sludge produced per year by Vancouver wastewater treatment plants is recycled and marketed as Nutrifor™ (Greater Vancouver Regional District 1999b).

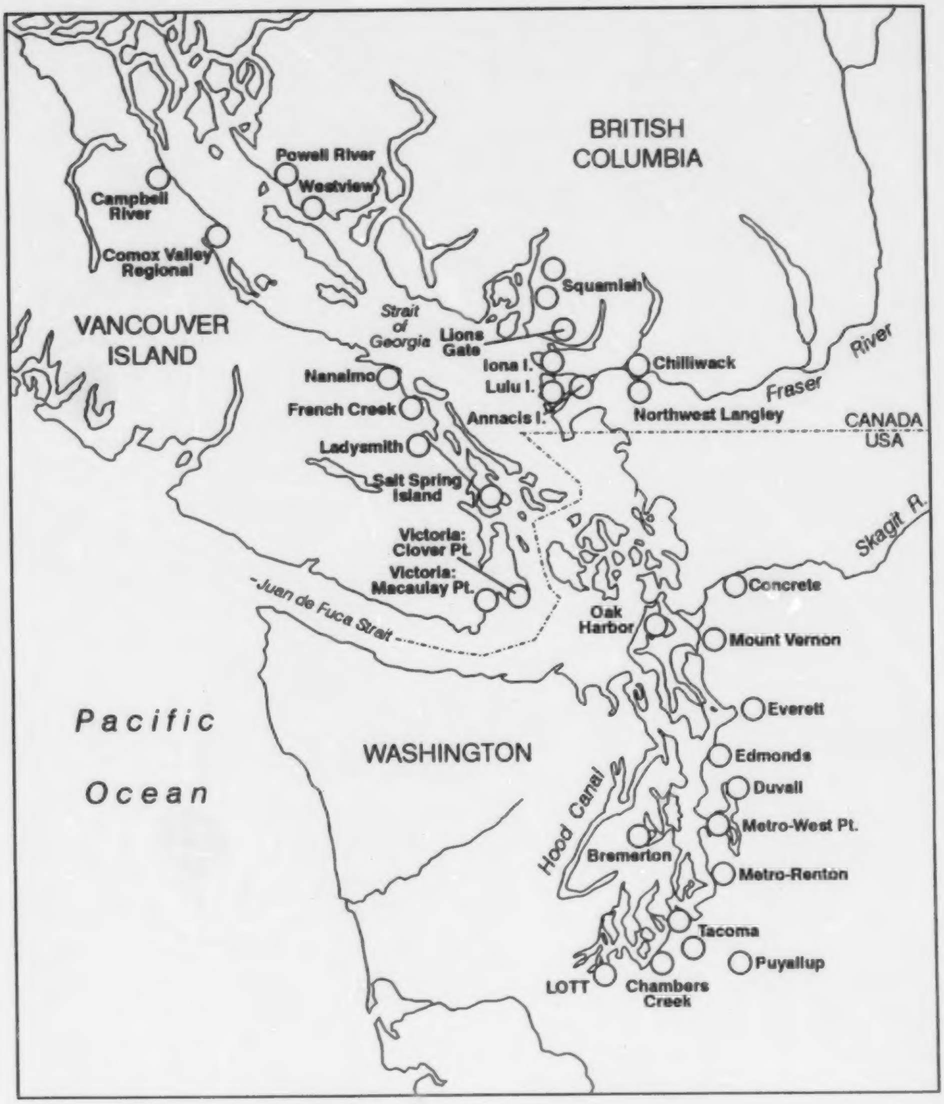

BRITISH COLUMBIA
Powell River
Westview
Campbell River
Comox Valley Regional
Squamish
Strait of Georgia
Lions Gate
VANCOUVER ISLAND
Iona I.
Chilliwack
Nanaimo
Lulu I.
Fraser River
French Creek
Annacis I.
Northwest Langley
CANADA
USA
Ladysmith
Salt Spring Island
Skagit R.
Victoria: Clover Pt.
Victoria: Macaulay Pt.
Concrete
Juan de Fuca Strait
Oak Harbor
Mount Vernon
Everett
Pacific Ocean
WASHINGTON
Edmonds
Hood Canal
Duvall
Metro-West Pt.
Bremerton
Metro-Renton
Tacoma
Puyallup
LOTT
Chambers Creek

Figure 24. Major sewage treatment plants discharge their wastewaters directly into the coastal waters frequented by southern resident killer whales (Strait of Georgia, Puget Sound and Juan de Fuca Strait). Source: (People for Puget Sound and Georgia Strait Alliance 1995).

5.2.3 Municipal Wastewater in B.C.

5.2.3.1 Regulation

In B.C., the Provincial *Waste Management Act* requires all municipalities to have a permit or a Liquid Waste Management Plan that involves source control, reduction of waste, and treatment. The Canadian *Fisheries Act* imposes penalties, including fines and/or imprisonment, for the deposition of "deleterious" substances into "waters frequented by fish"; municipal sewage may be considered a "deleterious substance". In Canada, regulation and monitoring of effluent discharges is generally conducted by the Provincial governments. Despite the *Fisheries Act*, municipalities have rarely been charged for routine sewage discharges, although there have been numerous prosecutions under the *Fisheries Act* for sewage spills. At the municipal government level, source control is possible through Sewer Use by-laws; however, human or financial limitations on source monitoring may impede enforcement (People for Puget Sound and Georgia Strait Alliance 1995).

5.2.3.2 Monitoring

The Georgia Basin Ecosystem Initiative (GBEI) (Environment Canada and the Ministry of Environment, Lands and Parks) has compiled information on the quality of wastewater discharged into the Strait of Georgia and Juan de Fuca Strait from WWTP. Total suspended solids (TSS) is one parameter used to characterize sewage effluent. Since treatment effectively reduces TSS and contaminants are generally bound to suspended solids (organic material), TSS provides a general measure of effluent quality. Effluent from Victoria and Vancouver's sewage treatment plants discharge the greatest amounts of TSS to the B.C. marine environment (Table 13). On March 20, 2001, Environment Canada issued Warning Letters pursuant to section 36(3) of the *Fisheries Act* to the Greater Vancouver Regional District for its 2 large primary treatment plant discharges which are toxic and therefore in violation of the *Fisheries Act*. Further assessment of the compliance status of these discharges is pending.

The GBEI has also identified organic contaminants in effluents from WWTP (Table 14). Polychlorinated biphenyls have been detected in a few samples from Victoria's Capital Regional District (CRD) WWTP effluents but levels were below the analytical detection limits of those from the Greater Vancouver Regional District (GVRD) (Table 14). The GVRD no longer monitors PCBs from CSOs and stormwater except when solids are analyzed. Polychlorinated biphenyl monitoring by the GVRD is generally recommended only for contaminated sites, particularly landfills containing old electrical equipment. Several new chemicals (e.g. nonylphenol) are poorly characterized in WWTP effluents despite their toxicity to biota and high concentrations in sediments; 30 t of nonylphenol ethoxylates were estimated to be in the sediments near the Iona outfall in the GVRD (Shang et al. 1999).

Table 13. Total suspended solids in coastal B.C. (data 1996-1998) are particularly high for sewage plants with only preliminary or primary treatment. Source: (Komex International Ltd. 1999; Quality Control Division of the Greater Vancouver Regional District 2000).

Sewage Treatment Facility	TSS (mg/L)	TSS (t/yr)	Treatment Level
Vancouver Island			
Campell River	9	45	2
Comox-Strathcona Regional District	18	93	2
Nanaimo Regional District	93	1008	1
Nanaimo Regional District-French Creek	22	61	2
Ladysmith, town of	44	46	1
District of North Cowichan-Chemanus	176	68	2
Duncan-North Cowichan	16	62	4
Victoria			
Clover Point	204	5309	0
Macaulay Point	230	3934	0
Central Saanich	20	39	2
Sidney	67	111	2
Mainland			
Powell River (Townsite)	13	19	2
Powell River-Westview	22	24	2
Squamish	28	39	4
Central Fraser Valley Regional District	13	193	2
Vancouver			
Iona Island	51	9883	1
Annacis Island	9	1517	2
Lions Gate	58	2040	1
Lulu Island	12	306	2
The District of Chilliwack	16	82	2

Table 14. Concentrations of contaminants in effluent from sewage treatment plants in the Georgia Basin. Source: (ENKON Environmental Limited 1999).

	Cd (mg/L)	Hg (mg/L)	Cu (mg/L)	Pb (mg/L)	Nonylphenol (μg/L)	γ-HCH (ng/L)	Fluoranthene (ng/L)	Pyrene (ng/L)	Aroclors 1254 (ng/L)	Aroclors 1260 (ng/L)
Vancouver										
Annacis Island	<0.0001	<0.00005	0.039	0.001	3.2	40	17	28	<6.7	<6.9
Iona Island	0.0005	0.00006	0.16	0.007	8.4	29	59	80	12	<4.6
Lulu Island	0.0032	0.0002	0.18	0.0069	8.4	11	94	120	<12	
Victoria										
Macaulay Point	0.005	0.01555	0.1102	0.0141			0.0005	0.00012		
Clover Point	<0.005	0.00659	0.857	0.07		0.000056	0.00015	0.000015		

The level of wastewater treatment in southwestern B.C. is largely primary and secondary, except for Victoria's (CRD) two largest outfalls, Macaulay Point and Clover Point, which have no treatment (Table 13). Various contaminants are discharged from the Macaulay outfall including PAHs (27 $kg \cdot yr^{-1}$), halogenated organics (230 $kg \cdot yr^{-1}$), non-halogenated organics (51 $kg \cdot yr^{-1}$), Cd (26 $kg \cdot yr^{-1}$), Hg (4.7 $kg \cdot yr^{-1}$), Cu (2300 $kg \cdot yr^{-1}$), and Pb (370 $kg \cdot yr^{-1}$). Concentrations of several contaminants measured in sediments near the Macaulay Point outfall are significantly greater than concentrations measured at reference sites; several sites have concentrations that are expected to cause adverse biological effects (Chapman et al. 1996). Toxicity testing has found that for stations near the outfall, survival of amphipods, polychaetes, and bivalve larvae was significantly reduced compared to reference sites. Although the greatest toxic effects occurred near the outfall, significant effects (compared to seawater control) were observed for all stations sampled (Chapman et al. 1996).

Overflow of raw sewage occurs during intense rain events when sewers overflow into storm drains that flow directly into the Victoria Harbour. Overflows also occur at Portage Inlet, The Gorge and the Outer Harbour (Victoria) (Mudge and Lintern 1999). In Greater Vancouver, CSO also contribute significant loads to the marine environment during overflow events. Annual loadings are particularly high for Clark Drive (7 833 935 $m^3 \cdot yr^{-1}$), English Bay (88 343 $m^3 \cdot yr^{-1}$), Crowe (370 142 $m^3 \cdot yr^{-1}$), Angus (1 495 806 $m^3 \cdot yr^{-1}$), Balaclava (526 554 $m^3 \cdot yr^{-1}$), Glenbrook (1 154 323 $m^3 \cdot yr^{-1}$), and Westridge (610 579 $m^3 \cdot yr^{-1}$) CSO discharges (Lee 1998).

Waste treatment facilities release treated wastewater from municipal, industrial, and domestic sources. Although most treatment facilities in B.C. are primary or secondary, two major facilities in Victoria continue to introduce untreated sewage into the marine environment. Contaminants detected in these discharges are largely metals and to a lesser extent PCBs and PAHs. New chemicals such as nonylphenols are poorly characterized in B.C. wastewater effluents but may be released to the marine environment in sufficient quantities to cause adverse environmental effects.

5.2.4. Municipal Wastewater in Washington

5.2.4.1 Regulation

The U.S. Federal *Water Pollution Control Act* (*Clean Water Act*) is used to regulate pollutant discharges to aquatic ecosystems. Under this legislation, all sewage treatment plants had to be upgraded to at least secondary treatment and a National Pollutant Discharge Elimination System (NPDES) was established. In Washington State, the Department of Ecology distributes NPDES permits to sewage treatment plants and other industries discharging wastewater. National water quality criteria have been established by the *Clean Water Act* to reduce concentrations of toxic contaminants in wastewater. In Washington State, enforcement of NPDES permit requirements has been uneven, with larger facilities being more closely monitored than smaller facilities. In addition, enforcement generally emphasizes voluntary cooperation to regulation rather than imposing fines and other penalties (People for Puget Sound and Georgia Strait Alliance 1995).

5.2.4.2 Monitoring

In the Puget Sound Basin there are 26 major and 44 minor municipal sewage treatment plants. All of these sewage treatment plants are required to have secondary treatment at a minimum. Loading information for metals and organic metals from these sewage treatment plants is not readily available, with the exception of the Metro-Renton and Metro-West sewage treatment plants (West et al. 1994).

Information on wastewater discharge to Puget Sound is limited. King County (Seattle) has conducted a comprehensive study of their combined sewer system. Since sewage and stormwater enters the marine environment without treatment during intense rain events and overflow, these combined systems are a particular concern; 9 billion L of untreated sewage was discharged from CSOs in this area between 1981-1988. As part of the NPDES, King County is only permitted to have four to six overflows per year. In addition, this jurisdiction is in the process of upgrading its wastewater conveyance and treatment system (Duwamish River and Elliott Bay Water Quality Assessment Team 1999).

Chemicals that have been identified in CSO discharges in King County include toxic PAHs and heavy metals (Cd, Hg, Cu, Pb). CSOs in this area are not significant sources for PCBs and tributlytin (TBT) in the water column. No apparent risks to marine biota (including salmonids) from exposure to metals, TBT or PCBs (Aroclor 1254 and 1260) in their prey have been identified. On the other hand, contaminant concentrations in sediments (PAHs, PCBs, and TBT) may present a health risk to benthic biota and the food chain. CSO controls alone, however, are unlikely to eliminate contaminant inputs into sediments, since other point sources continue to introduce significant quantities of contaminants into these marine waters (Duwamish River and Elliott Bay Water Quality Assessment Team 1999).

Information on discharges from sewage treatment plants was limited for Puget Sound. Studies on combined sewer overflows (CSOs) from King County suggest that most current risks from these sources are due to metals and PAHs.

5.3 PULP AND PAPER MILLS

The most significant quantities of waste produced by B.C. and Washington pulp and paper mills are generated during the pulping process. Of the three pulping processes (sulfite, kraft, mechanical), sulfite and kraft produce the most chemical waste since acids and caustics are used to separate cellulose fibers from lignin. In contrast, mechanical processes use physical pressure to separate cellulose fibers from lignin. Chlorine or chlorine based compounds may also be used with any of these three pulping processes to remove of lignin from cellulose and also to bleach the pulp.

Pulp mill effluent historically represented the largest source of dioxins and furans to the environment (Environment Canada and Federal/Provincial Task Force on Dioxins and Furans 1999). When monitoring between 1987 and 1989 revealed high concentrations of these chemicals in fish and shellfish near pulp mills, the Canadian and U.S. federal governments issued harvesting restrictions and began developing legislation to reduce the release of these chemicals.

In Canada, amendments to the Canadian *Fisheries Act* Pulp and Paper Effluent Regulations (PPER) in 1992, required pulp and paper mills that discharge to aquatic environments to ensure their effluent is not acutely lethal to fish by complying with new reduced biological oxygen demand (BOD) and TSS effluent limits. In addition, mills using chlorine in their bleaching process were required to measure dioxin and furan concentrations in fish found in waters near their discharge sites. All pulp mills were required to implement an Environmental Effects Monitoring (EEM) Program to ensure that fish and fish habitat are protected by the PPER and *Canadian Environmental Protection Act* Pulp and Paper Mill Chlorinated Dioxin and Furan Regulations (CDFR). A Local Monitoring Committee, comprised of mill employees, consultants, and Federal and Provincial Environment and Fisheries representatives, was established to review EEM programs' study design and results. EEM program requirements and the BC Ministry of Environment, Land and Parks (MELP) effluent discharge permit monitoring requirements have been integrated.

In the U.S., discharge limits for pulp and paper mills were set by the Environmental Protection Agency (EPA) in 1982. In Washington, these federal effluent limits were incorporated into the Department of Ecology issued NPDES permits. Both the federal *Clean Water Act* and Washington State's Water Pollution Control law provide regulations for wastewater discharged from pulp and paper mills.

In southwestern B.C. there are 10 operating pulp and paper mills that discharge their effluent directly or indirectly (via rivers) into the coastal marine environment (Table 15; Figure 23): 1. Norske Skog Canada (Crofton); 2. Pope & Talbot (Harmac); 3. Pacifica Papers (Port Alberni); 4. Norske Skog Canada (Elk Falls); 5. Western Pulp Limited Parnership (Port Alice) and five on the mainland: 6. Pacifica Papers (Powell River); 7. Western Pulp Limited Partnership (Squamish); 8. Howe Sound Pulp & Paper (Port Mellon); 9. Norampac Paper (New Westminster); 10. Scott Paper; (Boyd 2001, pers. comm.).

In Puget Sound, there are eight pulp and paper mills (Table 15; Figure 23): 11. Georgia Pacific; 12. Kimberly-Clark; 13. Sonoco; 14. Simpson Tacoma Kraft; 15. Stone-Consolidated; 16. Port Townsend Paper; 17. Rayonier (ceased operation in 1997); 18. Daishow America. These mills produce over 4 000 t of pulp and paper products each day including writing paper, cardboard, tissue paper, newsprint, cellophane and cellulose acetate (Kent 1996).

Table 15. Pulp and paper mills in B.C. and Puget Sound (numbers and names correspond to pulp and paper mills on Figure 23). Data from (Colodey et al. 1999; Kent 1996; Ochman et al. 1997).

	Mill Name (Location)	Type	Receiving Environment	Discharge ($m^3 \cdot d^{-1}$)	Bleach Used
	British Columbia				
	Vancouver Island				
1	Norske Skog Canada (Crofton)	Kraft	Marine	154,117	75-100% ClO_2
2	Pope & Talbot (Harmac)	Kraft	Marine	143,415	100% ClO_2
3	Pacifica Papers (Port Alberni)	CTMP	Marine	87,226	Peroxide
4	Norske Skog Canada (Elk Falls)	Kraft, TMP	Marine	167,837	100% ClO_2
5	Western Pulp Limited Partnership (Port Alice)	Sulphite	Marine	136,882	Chlorine
	Mainland				
6	Pacifica Papers (Powell River)	Kraft, CTMP	Marine	269,664	80-95% ClO_2
7	Western Pulp Limited Partnership (Squamish)	Kraft	Marine	65,054	65-100% ClO_2
8	Howe Sound Pulp & Paper (Port Mellon)	Kraft, TMP	Marine	85,087	60-100% ClO_2
9	Norampac Paper (New Westminster)	recycling	River	8,151	unbleached
10	Scott Paper (New Westminster)	Tissue	River	15,173	unbleached
	Washington				
11	Georgia Pacific	Sulfite	Marine	136,260	ClO_2
12	Kimberly-Clark	Sulfite MP	Marine	113,550	non-chlorinated compounds
13	Sonoco	N/A	River	738	unbleached
14	Simpson Tacoma Kraft	Kraft	Marine	94,625	ClO_2 (85%)
15	Stone-Consolidated	TMP	Marine	22,710	unbleached
16	Port Townsend Paper	Kraft	Marine	54,882	unbleached
17	Rayonier (Now Closed)	Sulfite	Marine	132,475	ClO_2
18	Daishow America	TMP	Marine	30,280	unbleached

TMP-Thermal Mechanical Pulp; CTMP-Chemical Thermal Mechanical Pulp; MP-Mechanical Pulp

Pulp and paper mill effluent toxicity has been reduced through the installation of primary and secondary treatment. Primary treatment involves screening and settling of suspended solids, while secondary treatment involves the bacterial decomposition of organic material (Canadian Environmental Protection Act 1991). By 1993, all B.C. pulp and paper mills had secondary treatment. In Washington, all pulp and paper mill effluent is treated at the primary or secondary level.

Many B.C. and Washington pulp and paper mills shifted from elemental chlorine bleaching to chlorine dioxide and other forms of bleaching by the 1990s (Yake et al. 1998). As a result, dioxins and furans discharged to the coastal waters of B.C. decreased by 96% between 1989 and 1995 (Figure 25), although residues have persisted in sediments near pulp and paper mills (Addison 1998). Total dioxins in effluents discharged to water by B.C. pulp and paper mills was 1.4 mg TEQ·day^{-1} and by Washington pulp and paper mills was 10.7 mg TEQ·day^{-1} in 1997 (Environment Canada and Federal/Provincial Task Force on Dioxins and Furans 1999; Yake et al. 1998). Pulp and paper mill effluent is no longer considered a major source of these contaminants to the marine environment in B.C. and Washington (Addison 1998).

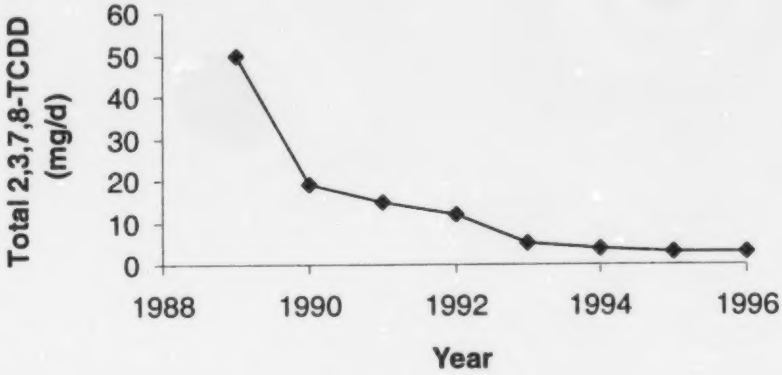


Figure 25. Concentrations of dioxins and furans discharged directly to coastal marine waters of B.C. have declined dramatically since their regulation in the late 1980s and early 1990s. Source: (Addison 1998).

Currently, the major source of dioxins and furans from pulp and paper mills is their release to the atmosphere through the burning of salt laden wood. Dioxins and furans released in this way reach biota in the marine environment through atmospheric transport and deposition.

Although pulp and paper mills released large quantities of dioxins and furans directly into the marine environment, regulations have resulted in dramatic reductions in the concentrations of these contaminants in sediments and biota. Dioxins and furans, however, continue to enter the marine environment, albeit at lower concentrations, either directly in effluent, or indirectly through incineration or disposal of sludge.

5.4 MINES

The principal risk of mining activities to marine mammals is related to their discharge of heavy metals into the aquatic environment. In mining, the process of extracting the desired mineral ore (e.g. gold, Cu, etc.) from rock produces considerable waste rock and tailings. Waste material containing sulphide-bearing minerals can oxidize and, when exposed to rain, can release large amounts of sulphuric acid that dissolves the waste rock to mobilize the enclosed metals. The resultant metal-rich solution (acid mine drainage or

AMD) can then leach into ground water or can be carried in runoff to the marine environment during precipitation events (AQUAMIN Working Groups 7 and 8 1996). Fully preventing AMD is impossible due to the large area of waste material that must be isolated from air and water. At best, AMD can be minimized by containing waste materials and runoff using liners and collection ditches, or by submerging the waste rock and tailings under water to prevent their exposure to oxygen.

In southwestern B.C., three actual or potential AMD sites (open-pit mines) may pose a threat to marine life (Figure 23). Two of these mines, *Mount Washington* and *Britannia Mine*, are no longer active, but continue to release metals to the marine environment. The third mine, *Myra Falls*, is still in operation.

The *Mount Washington Mine* (copper) on Vancouver Island operated for two years in the 1960s before closing. Although this mine only covered 40 ha of land, considerable quantities of waste rock (940 000 t) and ore (360 000 t) was excavated, both of which contained iron-copper-sulphides. The waste rock piles and the exposed mine tailings are located adjacent to the Tsolum River which discharges into the Strait of Georgia via the Courtenay River. Current concentrations of Cu in the water ranges from 17 to 110 ppb and loading from this mine continues to be extremely high. Although efforts have been made to reduce exposure of acid generating rock to the environment, the mining pit continues to contribute significantly to AMD and to the associated high Cu concentrations in the aquatic environment (AQUAMIN Working Groups 7 and 8 1996).

The *Britannia Mine* (copper and zinc), north of Vancouver, operated for 80 years, and is considered the most significant polluting mine in B.C. (McCandless 1995). Through a recent agreement, the former owners have agreed to contribute to the clean up of this mine site. Since this site closed in 1974, up to 1000 kg of Cu and zinc have been discharged each day (flow-rate: 4 million to 40 million L per day) through a pipe that lies on the bottom of Howe Sound, as well as via Britannia Creek. As a result, Howe Sound is the largest point source of Cu pollution in North America. In Britannia Bay, surface water concentrations are several times the toxic level for most marine organisms (AQUAMIN Working Groups 7 and 8 1996). Field studies in the Britannia Creek estuary and laboratory bioassays on Britannia Mine AMD have demonstrated the negative effects of Britannia mine's AMD on fish abundance (chum salmon) and mortality (for chinook salmon) and the toxicity of AMD to juvenile chum and chinook salmon (Barry et al. 2000).

Myra Falls Mine (zinc, copper, silver, lead, gold) covers 40 500 ha of Strathcona park. Mine tailings are dumped into holding ponds which overflow into Myra Creek and then into Buttle Lake which flows into the Campbell River. After it began operating, high levels of Cu and Pb were measured in fish (AQUAMIN Working Groups 7 and 8 1996).

To minimize and manage the environmental impact of AMD, a combination of remediation efforts, research, and special review processes for proposed mines are currently applied. Several mines in B.C. have ceased operations, including the Mount Washington mine, where Federal and Provincial legal options are currently being examined. Research efforts are being coordinated by a 1987 task force (B.C. Acid Mine Drainage Task Force) which involves the B.C. Mining Association and Provincial and Federal Governments. To prevent future problems from new mines, mine proposals must now undergo a provincial Mine Development Review Process that requires studies on potential AMD problems and prevention. New mining companies are now required to post bonds so that when the mines close, funds will be available for remediation and control.

Since most of the mining in Washington State is carried out a considerable distance from Puget Sound, there is little risk of metal leaching into the GPF marine environment. Most mining occurs at Echo Bay's Kettle River Lamefoot mine (Republic), with new mines being proposed in Okanogan County and exploration taking place in the Wenatchee gold belt (Skamania County) and near Metaline Falls.

Acid mine drainage is an environmental issue in coastal B.C., where several abandoned mines discharge heavy metals into the marine environment. In Washington State, no acid mine drainage sites discharge directly into Puget Sound. Clean-up efforts are being conducted in B.C. to reduce the environmental impacts of mine drainage. In addition, new regulations and research are focused on preventing these problems from occurring at future mine sites. Since metals are largely not bioaccumulative in aquatic food chains, impacts of mines on killer whales are likely to be indirect, such as AMD impacts on killer whale prey survival and habitat quality.

5.5 OIL SPILLS AND REFINERIES

Although the chemical ingredients in oil (petroleum hydrocarbons) can generally be metabolized and excreted by marine mammals, acute or chronic exposure may pose a toxicological risk to these organisms. Effects of acute exposure to petroleum products can include changes in behaviour and reduced activity (from neural intramyelinic edema and thalamic nuclei damage), conjunctivitis, and epidermal irritation, in marine mammals (Spraker et al. 1994).

Following the *Exxon Valdez* 41 million L oil spill in Prince William Sound, Alaska in 1989, 13 adult killer whales disappeared. In addition to this apparent adult mortality, no calves were born immediately after the spill (1989-1990). Increasing tanker traffic, the large number of oil refineries and pipelines, and renewed interest in offshore oil exploration in B.C. and Washington, present an oil spill risk in this area.

Juan de Fuca Strait, Strait of Georgia and Puget Sound are among the busiest waterways in the world, with vessel traffic (oil, cargo, passenger) going to and from ports in B.C. and Washington State. Considerable vessel traffic moves through Vancouver since it is the largest port in Canada (cargo: 72 million t per year) (Adair 1998). In 1996, a total of 804 oil tankers passed through Washington waters bound for Puget Sound ports, Canadian ports, the Columbia River and Grays Harbour (Neel et al. 1997). Puget Sound has a particularly large number of vessels transporting oil since ports within this estuary are the closest in the lower U.S. to the crude oil supply in Valdez, Alaska. Inbound oil tankers transport crude oil to Washington's refineries, while outbound tankers transport refined oil from Puget Sound to other states along the U.S. west coast (Oregon and California) (Neel et al. 1997).

Two major oil spills have taken place in the past in the coastal waters of B.C. and Washington. These include the ARCO *Anchorage* tanker spill (1985) near Port Angeles (Washington) which discharged 904 447 L of crude oil to marine waters, and the *Nestucca* spill (1988) which discharged 875 000 L of bunker C oil to the marine waters off the southern coast of Washington State (Figure 23) (Harding and Englar 1989; Waldichuk 1989). The *Nestucca* spill was particularly damaging since it led to the closure of mollusc and crab fisheries and threatened local sea otter populations. In addition to these spills, numerous "close calls" have occurred in coastal B.C./Washington following groundings, collisions, power loss, and poor vessel condition (Neel et al. 1997).

Although vessel spills represent 37% of all oils spilled in Washington since 1970, other discharges of oil to coastal waters have resulted from oil refinery (37%) and pipeline (26%) spills (Neel et al. 1997). Puget Sound is a major petroleum refining center in the U.S.; four oil refineries are situated in this area: Mobil Oil (Ferndale), Shell Oil and Texaco (Anacortes), and the U.S. Oil (Tacoma) (Figure 23). Two major spills from refineries include a spill of 151 000 L of crude oil at the Texaco refinery (1991) and a 2 270 579 L crude oil spill at the U.S. Oil refinery (1991). Only the Texaco refinery spill resulted in significant discharges to Puget Sound. In addition to being transported in barges and tankers, refined oil is also transported through pipelines from Washington to other states (Oregon and California). Five major pipelines are situated in Washington: Trans-Mountain, Olympic, McChord, Chevron, and Yellowstone. In addition to spills, the treated wastewater from each of the refineries is discharged into Puget Sound; in 1996, 65 317 kg of oil and grease were discharged into Puget Sound from these refineries (Neel et al. 1997).

After the *Nestucca* and the *Exxon Valdez* vessel spills, the Pacific States (Alaska, Washington, Oregon, California, Hawaii) and the province of British Columbia (Canada), formed a cooperative Oil Spill Task Force in 1989 to coordinate prevention and oil spill response efforts. These goals are accomplished through the sharing of information and resources by these states and province and the development of consistent regulatory standards at both the national (Canada/U.S.) and state/provincial (Alaska, Washington, Oregon, California, B.C.) levels. The task force produced a report in 1990 that provided spill prevention/response recommendations. The majority of these have been incorporated into state and provincial regulations and programs. In addition, they have also been incorporated into the U.S. Federal *Oil Pollution Act* (1990) and the Canada *Shipping Act* (1993). In Washington State, oil spill prevention and control is managed by the Department of Ecology. However, it was not until 1991 that management was centralized, amalgamating responsibility for several spill related activities including spill prevention, management of spill response preparedness, oil spill control, and coordination of environmental impact assessments. In addition, the Washington State Office of Marine Safety was created in 1991 to provide further assurance that the frequency of oil spills would be reduced. Although oil spills increased on a global scale by 41 % between 1987 and 1995 (total in 1995: 283 822 321 L), spills in Washington appear to have decreased (Figure 26) (Neel et al. 1997).

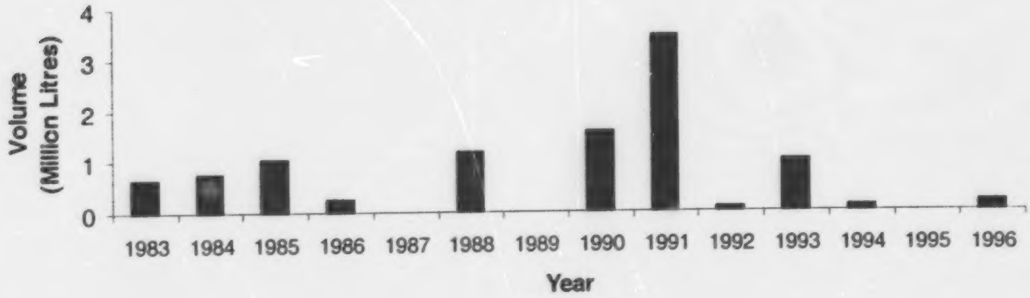


Figure. 26. Although oil spill risk is still relatively high in Washington, the number of major spills (> 37, 842 L) have decreased since 1991.
Source: (Neel et al. 1997)

Oil spill risk in coastal B.C. and Washington marine waters is relatively high due to the considerable vessel traffic and the presence of oil refineries and pipelines in these areas. Two major oil spills in Washington State led to coordinated spill prevention and response efforts by Canada and the U.S. (Oil Spill Task Force: 1989). Health risks to killer whales are largely related to disaster/spill scenarios (i.e. acute exposure and toxicity) rather than chronic exposure to the metabolizable hydrocarbons associated with oil.

6.0 CONTAMINANT NON-POINT SOURCES IN BRITISH COLUMBIA AND WASHINGTON

6.1 OVERVIEW

Non-point source pollution enters the marine environment from diffuse rather than localized sources. Non-point source pollution includes atmospheric transport and urban/agricultural runoff. Since it is generally difficult to identify the original source responsible for these contaminant inputs to the environment, regulation and control of their release presents a considerable challenge. The approach generally taken to control non-point source pollution is to target an entire industry or sector (to regulate and monitor their emissions and discharges) and to provide education and information on minimizing the release of toxic chemicals.

Since non-point source pollution is a complex management issue, all levels of government in B.C. (federal, provincial, and municipal) are involved in developing appropriate legislation and enforcement. At the federal level, various acts that are used to manage non-point source pollution include the Canadian *Fisheries Act*, the Canadian *Environmental Protection Act*, and the Canadian *Environmental Assessment Act*. At the provincial level, the *Waste Management Act*, the *Environmental Management Act*, the *Environmental Assessment Act*, the *Pesticide Control Act*, and the *Municipal Act* are used to manage non-point source pollution.

In Washington State, non-point source control only became coordinated between different levels of government in 1987. Under the *Clean Water Act*, the state controls non-point source pollution. In 1989, Washington produced a non-point source pollution assessment and management program. Improvements to the control of non-point source pollution also occurred after 1990 when the *Coastal Zone Management Act* was amended to address land-use and non-point pollution for the first time. Watershed management approaches have also been adopted relatively recently to manage both point and non-point source pollution. This resulted in the expansion of the Department of Ecology's (Ecology) Total Maximum Daily Loads program to include non-point source loading.

6.2 ATMOSPHERIC DEPOSITION

6.2.1 Long Range Transport of Atmospheric Pollutants (LRTAP)

Contaminants in either particulate or gas phase can be transported great distances in the atmosphere from their site of origin. These can include PCBs, dioxins and furans, fossil fuel combustion by-products (PAHs), heavy metals (particulate Cd and gaseous Hg, Cu, Pb) and persistent organic compounds such as pesticides (hexachlorocyclohexane, toxaphene, DDT, lindane, etc.).

In the North Pacific, air moves from Eurasia to North America, predominantly along mid-latitudes in a circulation pattern called the westerlies. Movement of air masses out of Asia and across the Pacific Ocean is most pronounced in the winter and spring, with the approximate time to traverse the Pacific being 5-10 days. As a result of this general air circulation pattern, pollutants from Asia have been detected as far east as Washington State (Jaffe et al. 1999). A large dust storm comprising metals of Chinese origin was tracked using satellite remote sensing from China as it moved to North America (Wilkening et al. 2000).

Although high concentrations of PCBs reported in southern resident killer whales may be partly attributed to local (coastal) sources, contamination of their food supply might also occur in the open ocean due to atmospheric deposition of pollutants into marine areas where salmon feed and grow (Ross et al. 2000). Studies on the Fraser River watershed in B.C. suggest that atmospheric transport of pollutants from Asia and elsewhere likely contaminated the sediments and biota of remote lakes (Macdonald et al. 2000b). Also attributed to atmospheric transport processes are high concentrations of POPs observed in snow from the Canadian Rocky Mountains (Blais et al. 1998). In coastal Washington, episodic transport of pollutants from Asia has been observed at the Cheeka Peak Observatory during spring (Jaffe et al. 1999).

A large scale program to study transport of pollutants in the Pacific called the Pacific Exploratory Mission (PEM)-West Campaign was established in 1991 and in 1994. Other international research programs that were designed to further knowledge of atmospheric transport and fate of pollutants include the following (Wilkening et al. 2000):

- Asia-Pacific Atmospheric Research Experiment (APARE), conducted under the International Global Atmospheric Chemistry Program (IGAC)
- the Environment Agency of Japan's Perturbation by the East Asian Continental Air Mass to the Pacific Oceanic Troposphere (PEACAMPOT) Program
- the U.S. National Aeronautics and Space Administration (NASA)'s Pacific Exploratory Mission in the Western Pacific Ocean
- University of California Pacific Rim Aerosol Network (UC PacRim).

In addition, several proposed programs include the following:

- Aerosol Characterization Experiment-Asia (ACE-Asia)
- TRAnsport and Chemical Evolution over the Pacific (TRACE-P)
- Inter-Continental Transport and Chemical Transformation (ITCT) Program
- Mercury and Fine Particle Monitoring at Cheeka Peak Observatory in Washington, U.S.

Research on long range transport of atmospheric pollutants in the North Pacific is only in its early phases, with considerable gaps in knowledge pertaining to the transport and fate of pollutants across the Pacific. The current and proposed programs on atmospheric pollutants will enhance understanding of these issues through concerted international and interdisciplinary efforts.

Contaminants can be transported from the western to eastern North Pacific (Eurasia to coastal B.C. and Washington), through atmospheric processes associated with prevailing westerlies. Although high contaminant concentrations in resident killer whales partly reflects local contamination in B.C. and Washington State, the atmospheric delivery of POPs of Eurasian origin to Northeast Pacific food chains is also likely to contribute to their contaminant burdens.

6.3 LANDFILLS

Despite recycling and waste reduction programs, Canadians and Americans produce 1.6 kg of solid waste per day, which is disposed of in landfills. To limit the amount of contaminants present in garbage from reaching the environment, most landfills today are designed to isolate industrial and domestic waste from the environment. By limiting the exposure of waste to both water (precipitation) and air, decomposition is reduced along with the associated production of leachate and gas. Liners and capping methods are used to reduce the exposure of waste to the atmosphere and groundwater and a combination of pipes and wells are used to control and monitor the leachate that is produced. Gas that is generated from waste in landfills is generally burned on site with a flare or is recycled as fuel.

Although operators of most municipal landfills do not permit the disposal of hazardous materials, disposal of small quantities still occurs. Even when not permitted, households and small businesses may dispose of paints, paint thinners, pesticides, cleansers, medicines, cosmetics, batteries, and oil at landfills. These products may then enter the marine environment when the landfill site is not adequately contained or may contaminate ground and surface water.

Before the mid 1980's, most landfill sites in B.C. were selected based on proximity to users and topography. New legislation was subsequently enacted, requiring each Regional District to prepare a Solid Waste Management Plan (SWMP). In 1993, the BC MELP prepared a "Landfill Criteria for Municipal Solid Waste". Although domestic and small business waste was classified as hazardous under the Hazardous *Waste Management Act* in Washington prior to 1991, disposal options were limited. In 1985, household hazardous wastes were included as moderate-risk waste under the state *Hazardous Waste Management Act*.

6.3.1 British Columbia Landfills

In B.C., the largest landfills are situated near the province's two main urban centres, Vancouver (City of Vancouver Landfill and Cache Creek Landfill) and Victoria (Hartland Landfill). The City of Vancouver landfill collects 440 000 t of waste per year, Cache Creek collects 500 000 t and Victoria's landfill collects 150 000 t per year. Intermediate sized landfills include the Whistler (15 000 t per year) and Squamish (12 000 t per year) landfills. Small landfills include the Heffley Creek (4 500 t per year) and the Savona Landfill (prior to closure: 700 t per year). Very small and remote landfills include Manson Creek Landfill (20 t per year) near Fort St. James.

In B.C., as part of the GBEI, some chemicals have been measured in leachate from these landfills (Table 16). Although the major group of chemicals detected in leachate has been metals, other groups are not regularly monitored; information on the discharge of leachate (including PCBs) and gas from landfills is limited. The GBEI only recommends monitoring landfill leachate for PCBs in cases where disposal of PCB equipment is known or suspected (ENKON Environmental Limited 1999).

Table 16. Concentrations of chemicals in leachate discharged from major coastal British Columbia landfills. Source: (ENKON Environmental Limited 1999).

	PCBs (mg/L)	Dioxins (pg/L)	PAHs (mg/L)	Metals (mg/L)				Pesticides (mg/L)	
Name of Landfill		(2,3,7,8-TCDD)	(naphthalene)	Cd	Hg	Cu	Pb	endosulfan	lindane
Burns Bog (Vancouver)	<0.001	<1.7	0.013	<0.05	0.3	<0.07	0.25	<0.002	<0.001
Lions Gate Landfill (Vancouver)				0.01		0.01	0.05		
Coquitlam				0.001		0.01	0.07		
Langley				0.003	0.0001		0.007		
Hartland (Victoria)				0.001	0.00005	0.019	0.003		

6.3.2 Washington Landfills

Landfill sites in Washington that have the potential for discharging contaminants to the aquatic environment are included in the EPA's Superfund Program. Sites that may present a health risk, particularly to humans, can be designated a National Priorities List (NPL) site. Once added to this list, a site is assessed to determine if further investigation is required and whether further evaluation takes place or clean-up is initiated.

In the Puget Sound Region, five landfills are designated as NPL sites (Tulalip Landfill, Old Navy Dump, Seattle Municipal Landfill, Midway Landfill, Tacoma Landfill, and Hidden Valley landfill). A sixth landfill, the U.S. Army Fort Lewis Landfill #5, was recently removed from the NPL list after a sufficient clean up program was conducted.

Tulalip Landfill (Marysville, Washington)

Approximately four million t of commercial, industrial and hospital waste were disposed of at this landfill between 1964 to 1979. It was placed on the NPL list in April 25, 1995. Surrounding slough water, which flows directly into northern Puget Sound, contains concentrations of metals (Cd, Cu, Pb) that exceed the EPA's Maximum Contaminant Levels established under the *Safe Drinking Water Act*, and the Marine Ambient Water Quality Criteria established under the *Clean Water Act*. In addition to metals, leachate at the site is also contaminated with PCBs. By April 2000, 40 ha of the landfill were covered, with a total coverage of 60 ha designated as a final goal.

Old Navy Dump/Manchester Lab

This dump, situated in an old tidal lagoon, stores over 53 million L of waste produced by on-site activities including the construction, repair, and maintenance of submarines and a firefighting school. Cadmium, Cu, Pb, and PCBs have leached from this site into surrounding sediment and water of Puget Sound. Clean up began in June of 1999.

The Seattle Municipal Landfill (Kent Highlands)

This site, occupying 20 to 30 ha, was used by the City of Seattle to dispose of municipal and industrial waste and industrial sludge. Heavy metals are a major contaminant in the leachate from this site. Clean up of the site, completed September 1995, involved directing leachate using an impermeable cover and ditch system to a stormwater retention pond.

Midway Landfill (Kent Washington)

This landfill contains 2.3 billion L of industrial, wood, and demolition waste, collected between 1966 and 1983. In 1983, the landfill was covered with silt and fine sands. In 1985, groundwater outside the boundaries of the landfill was found to contain heavy metals, PCBs, and volatile organic compounds (VOCs). Remedial measures have included capping the site, landfill gas control, and a stormwater and drainage control system. Consequently, the quality of the groundwater downgradient of the landfill has improved since 1985.

Tacoma Landfill (Tacoma, Washington)

Operators of the Tacoma Landfill, covering 90 ha, started to accept waste from municipal, industrial, construction, and demolition sources, and bulk wastes in the 1960s. About 4 million t of refuse was deposited at the landfill, including hazardous waste. Groundwater that flows to Leach Creek was found to contain heavy metals. A landfill cap has been completed over the refuse area, along with two groundwater pump and treatment systems. As a result, groundwater quality between the landfill and Leach Creek has been improved.

Hidden Valley Landfill (Puyallup)

The operators of this 30 ha landfill began accepting liquid, and solid, and industrial waste in 1967. Subsequently, 20 ha of this landfill was closed and capped. Currently, all waste is disposed of in a 10 ha lined area and leachate is collected and treated. The landfill stopped waste collection in 1998. Metals contaminate groundwater at this site. For remediation, unlined areas of the landfill have been capped. Other remedial plans are being developed.

Landfills may release toxic, persistent chemicals into the aquatic environment through the production of leachate. Metals have routinely been measured in leachates from B.C., with most of this being diverted to wastewater treatment plants prior to discharge. Information on closed landfills in B.C. that represent a source of contaminants to the marine environment is limited. In Washington State, several landfill sites have been placed on a National Priority List and are designated for clean-up since they represent contaminant sources for the marine environment.

6.4 PEST MANAGEMENT PRACTICES

6.4.1 Agricultural and Urban Pesticides

In B.C., 61 668 kg of pesticides were used in 1991. In the Puget Sound basin of Washington State, approximately 1 270 000 kg of pesticides were used in 1988 (Tetra Tech Incorporated 1988). Most pesticide use occurs in urbanized areas; in the Puget Sound region, urban use accounts for 38% of total pesticide use while agriculture accounted for only 12% of total use (Figure 27). Since most of the urban centers in southwestern B.C. and the Puget Sound Basin continue to grow, increasing use of pesticides can be expected in both urban and agricultural settings.

Pesticides frequently detected in the GPF marine environment tend to be those most commonly applied to the adjacent terrestrial environments (Bortleson and Davis 1997; Voss et al. 1999). Out of the 274 pesticide active ingredients used in B.C., the most common include creosote, borax, glyphosate, pentachlorophenol, sodium carbonate, mancozeb, captan, diazinon, azinphos-methyl, metiram, and 2,4-D (Norecol Dames & Moore 1997). In Puget Sound, commonly used pesticides include 2,4-D, prometon, diazinon, malathion, methyl-bromide, sulfuryl fluoride, simazine, dicamba, and trichlopyr (Bortleson and Davis 1997; Voss et al. 1999). Application rates are important, but long term exposure to aquatic organisms also depends on the pesticide's persistence and water solubility.

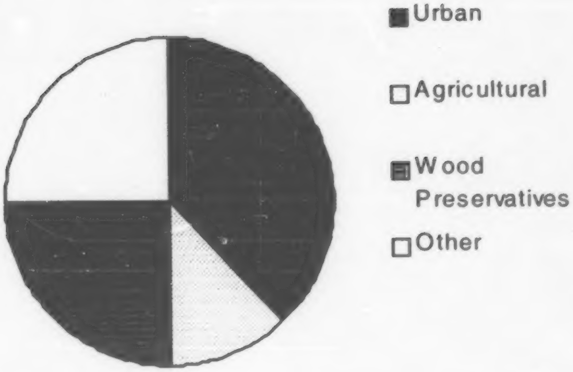


Figure 27. Urban pesticide use accounts for the largest proportion of total pesticide use in the Puget Sound Basin. Source: (Tetra Tech Incorporated 1988).

Although most pesticides currently used in Canada and the U.S. have short soil half lives, several are of intermediate persistence. Consequently, trace amounts of pesticides detected frequently in wells and runoff in the Fraser Valley, B.C., include dinoseb, methoxychlor, endosulfans, malathion, simazine, lindane, metalochlorparathion, and trufluralin (Cox and Liebscher 1999; Nowell et al. 1999). In the U.S., frequently detected pesticides in sediment and freshwater biota include 2,4-D, dicamba, diuron, trifluralin, chlorpyrifos, dicofol, endosulfan, and lindane (Nowell et al. 1999). In the Puget Sound Basin, pesticides detected in streams and ground water include atrazine, dicamba, diazinon, prometon, simazine, tebuthiuron, and 2,4-D (Bortleson and Davis 1997; Bortleson and Ebbert 2000). Pesticides that have been detected in biota far from their application site (e.g. mussels in Puget Sound) were also those of intermediate persistence. These included endosulfan, lindane, and pentachlorophenol (Johnson and Davis 1996). Glyphosate (Roundup™) and its metabolite AMPA, with high use in both Puget Sound (124 698 kg·yr^{-1}) and Southern B.C. (98 208 kg·yr^{-1}), can be moderately persistent depending on prevailing soil conditions (e.g. pH, moisture content, temperature, microbial activity, etc.) (Torstensson et al. 1989).

In addition to being persistent, several currently used pesticides also have a moderate bioaccumulation potential, including lindane (annual use in B.C.: 272 kg; Puget Sound: 31 770 kg) (Table 17). Therefore, these pesticides may present a greater health risk to high trophic level organisms.

Table 17. Several currently used pesticides in B.C. and Washington have a high bioaccumulation potential and may therefore present a health risk to biota. Source: (Ewing 1999).

Pesticide	Category	Bioaccumulation Factor	Species
Carbaryl	Insecticide	30	golden ide[1]
Chlorpyrifos	Insecticide	1374	rainbow trout[2]
Diazinon	Insecticide	60	carp[3]
Dichlobenil	Herbicide	40	golden ide[1]
Pentachlorophenol	Insecticide	251-5370	rainbow trout[3]
Permethrin	Insecticide	1700-3300	fathead minnow[4]
Pentachlorophenol	Fungicide	100	rainbow trout[5]

1=(Freitag 1985) 4=(Smith and Stratton 1986)
2=(Racka 1993) 5=(Hattula et al. 1981)
3=(Howard 1991)

As part of the GBEI, 11 pesticides have been placed on Environment Canada's list of toxic substances (ENKON Environmental Limited 1999) (Table 18). The goal of listing was to characterize information on sources, concentrations, and loadings of these chemicals to wastewaters prior to the development of a management strategy for 2003.

Table 18. Pesticides on Environment Canada's list of toxic substances, their associated aquatic life guidelines, and total quantities sold or used in B.C. in 1995. Source: (ENKON Environmental Limited 1999; Norecol Dames & Moore 1997).

Pesticide	Aquatic Life Guidelines (ug/L)	Use (kg)
A. Agricultural/Urban Use		
Atrazine	10	10 928
Dinoseb	0.05	minimal
Endosulfan I or II; Endosulfan sulphate	0.02	7 308
Hexachlorobenzene	na	not in use
γ-HCH (Lindane)	0.01	being phased out
Malathion	0.1	6 523
Metolachlor	8	6 807
Methoxychlor	0.04	minimal
Parathion	na	3 969
Simazine	10	10 639
Trifluralin	0.1	4 125

Although most current use pesticides are applied to the terrestrial environment, several enter the marine environment through runoff or atmospheric drift. Pesticides that present a particular risk to marine mammals are those that are persistent, bioaccumulative, and toxic, or those that affect habitat quality of killer whale prey.

6.4.2 Antisapstain chemicals, wood preservatives, and slimicides

Of the 8 674 920 kg of pesticides purchased in 1995 in B.C., 7 687 656 kg (80%) were anti-microbial chemicals, used mainly for long-term (wood preservation) and short-term (anti-sapstain) wood protection (Norecol Dames & Moore 1997).

For long term protection from insects, fungus and marine borers, wood is preserved using pesticides such as chromated copper arsenate (10.5% of all pesticide usage in B.C.), pentachlorophenol, ammoniacal copper arsenate, and creosote (Norecol Dames & Moore 1997). Of particular environmental concern are the chlorophenols, which are persistent, can bioaccumulate, and are toxic to aquatic organisms. These chemicals have been detected in wood preservation plant wastewater discharge, urban runoff, landfill leachate, sewer outflows, and WWTP effluent in the Georgia Basin (ENKON Environmental Limited 1999).

For short term protection, wood is preserved using anti-sapstain pesticides. These types of pesticides are used by lumber mills to protect recently produced lumber from fungus and mold during shipment. In the Georgia Basin, chlorophenol use as an anti-sapstain chemical has been replaced with didecyl dimethyl ammonium chloride (DDAC) and 3-iodo-2-propynyl-butyl carbamate (IPBC). These pesticides are toxic to aquatic organisms; DDAC disrupts cellular membranes consequently damaging gills and digestive tracts and IPBC is an acetylcholinesterase inhibitor (Szenasy 1999). Acute toxicity (96-h LC50) of Bardac 2280 (80% DDAC) can vary in fish from 330 ppb-2000 ppb and acute toxicity of Troysan Polyphase P-100 (97% IPBC) can vary in fish from 95 ppb to 1900 ppb (Farrell and Kennedy 1998). Since analytical methods for detecting DDAC and IPBC have only recently been developed these chemicals have not been commonly monitored in the aquatic environment. Draft interim guidelines for the protection of freshwater life in Canada has been set at $1.5\ \mu g{\cdot}L^{-1}$ for DDAC and $1.9\ \mu g{\cdot}L^{-1}$ for IPBC. In Fraser River sediments downstream from several lumber mills, concentrations of DDAC were on average $0.91 \pm 0.29\ \mu g{\cdot}g^{-1}$ dry weight ($n = 8$) and of IPBC were $0.35 \pm 0.14\ \mu g{\cdot}g^{-1}$ dry weight ($n = 8$) (Szenasy 1999).

Several wood preservatives and antisapstain chemicals leach into the marine environment from treated wood. Of particular concern are chlorophenols, that are persistent, bioaccumulative and toxic, as well as DDAC and IPBC.

6.4.3 Antifouling agents (organotins)

The main antifouling agent used on vessels that is a concern for marine life is tributyltin (TBT) and its breakdown products dibutyltin (DBT) and monobutyltin (MBT). Although use of TBT was banned on small vessels (< 25 m) in Canada (1989) and the U.S. (1988), its use is still permitted on larger ocean-going and aluminum-hulled vessels (Harrison et al. 1994). In many developing nations the use of TBT continues to be unregulated. As a result, vessels that enter B.C./Washington harbours from other parts of the world will likely continue to contribute significant quantities of TBT to the coastal environment (Chau et al. 1997; Macdonald and Crecelius 1994).

Butyltins can disrupt endocrine function in biota even at low concentrations (0.001 to 0.24 $\mu g \cdot L^{-1}$) (ENKON Environmental Limited 1999). They are also bioaccumulative.

Although concentrations have generally declined in coastal waters of Canada and the U.S., sediment core data suggests butyltins have not declined recently in large industrial harbours (Addison 1998; Stewart and Thompson 1997). In the both Puget Sound and the Strait of Georgia, TBT concentrations are highest in sediments near marinas, harbours and shipyards, with concentrations ranging from 100 to 10 000 μg/kg (Macdonald and Crecelius 1994).

The antifoulants TBT, DBT and MBT have also been measured in various fish and invertebrate species. For example, concentrations in B.C. chinook salmon were 0.2-537 $\mu g \cdot kg^{-1}$ (TBT), 0.6-725 $\mu g \cdot kg^{-1}$ (DBT), and 0.4-129 $\mu g \cdot kg^{-1}$ (MBT) (Garrett and Goyette 2000). In a recent survey of North American birds, the highest levels of butyltins (up to 1,100 $\mu g \cdot kg^{-1}$ wet wt) were detected in seaduck (*Melanitta perspicillata*) livers collected near marinas and harbours of coastal British Columbia; butyltin concentrations were particularly high in birds collected from Vancouver's Burrard Inlet (Kannan et al. 1998).

Based on continued inputs of butyltins into coastal marine environments and its moderate residence time (estimated half-life: 8.7 years) (Stewart and Thompson 1997), marine organisms in these habitats will continue to be exposed to these anti-fouling chemicals.

Although tributyltin (TBT) concentrations in the sediments of recreational harbours have declined since partial regulation in the late 1980s in North America, its continued use on vessels larger than 25 m and aluminum-hulled vessels has led to a stabilization of tributyltin and its metabolites in industrial harbour sediments. As a result, this chemical class continues to represent a health risk for marine biota in certain areas.

6.4.4 Pesticide Reduction Management

To reduce pesticide use in B.C., the B.C. *Pesticide Control Act* has been recently revised to encourage Integrated Pest Management (IPM) practices, which combines biological pest control methods with chemical control methods. Organic farming which restricts pesticide use on crops is also increasing in B.C.; from 4 300 ha to 1 1500 ha from 1997-1999.

In Washington, decreased pesticide use has been largely voluntary with an emphasis on public education. Washington State University (W.S.U.) and the W.S.U. Cooperative extension have been involved in research and educational programs largely focused on pesticide use in the farming industry. Although these efforts have been successful in agricultural pesticide use, they have not supported the domestic user that accounts for 20% of the total pesticide use in Puget Sound. As a result, pesticides may be incorrectly or inappropriately applied increasing their likelihood of entering the surface and ground water supplies. In Washington some local governments and utilities have initiated IPM programs for roadside and utility rights-of-way.

7.0 POORLY REGULATED CHEMICALS

The high cost of adequately testing all chemicals for environmental effects before their use (approximately $1.5 million per chemical) (Canadian Council of Resource and Environment Ministers 1986), including the difficulty in testing for synergistic effects among chemicals, has often resulted in the implementation of controls only after an environmental problem has been detected. Although 200-1000 new chemicals are released into the environment globally each year, the only requirement for a company manufacturing or importing a new chemical into Canada is to notify Environment Canada and to specify if the company has any information on the chemical's toxicity or environmental impacts. Several minimally regulated new chemicals have been recently detected in the global environment. New chemicals of greatest current concern include those which are highly persistent, bioaccumulative and toxic. These include chlorinated paraffins, brominated flame retardants, fluorinated organic surfactants, polychlorinated naphthalenes, alkylphenols, and polychlorinated terphenyls (Table 19).

7.1 POLYCHLORINATED PARAFFINS (PCPs)

Polychlorinated paraffins (PCPs) are chlorinated *n*-alkanes of varying carbon chain lengths (10 - 30) and chlorine content (30 - 70% by weight) (Government of Canada et al. 1993a). Two thousand types of PCPs are used commercially; these have been classified into three groups based on the length of their carbon chain: short chain (C_{10} - C_{13}), medium chain (C_{14} - C_{19}), and long chain (C_{20} - C_{30}). Since PCPs do not occur naturally, the sources of these chemicals are entirely anthropogenic. Key applications include flame retardants, placticizers, paints, sealants and additives in lubricating oils (Government of Canada et al. 1993a; Tomy et al. 1999). Despite their persistence and bioaccumulation potential, global use of PCPs for 1993 was reported to be ~300 $kt \cdot yr^{-1}$. In Canada and the U.S., annual use in 1998 was estimated at 3.5-5 kt and ~45 kt, respectively (Tomy et al. 1999).

The physicochemical properties of PCPs are poorly described, reflecting the large variety and complexity of their mixtures, as well as limitations in analytical methods. In general terms, PCPs are highly persistent, have high log K_{ow} coefficients (5-12), have been observed to bioconcentrate as much as 139,000 times in biota, and can be transported great distances in the atmosphere (Henry's Law Constants are similar to toxaphene).

Of all the PCP groups, those with short-chain (C_{10}-C_{13}) lengths present the greatest toxicological risk to organisms since they are the most widely used and appear to have the greatest toxicity (Tomy et al. 1999). In laboratory animals, PCPs produce toxic effects in the kidney and liver; the highest dose rate that does not cause adverse effects was 30 $mg \cdot kg^{-1} \cdot day^{-1}$. In Canada, PCPs are listed on Environment Canada's Priority Substances List and in the U.S. they have been placed on the EPA's Toxic Release Inventory.

Also a result of their complexity, there has been little monitoring of PCPs in the environment. In one study, PCP concentrations were measured in sediments from six Canadian lakes: concentrations of PCPs in southern lakes were generally higher (e.g. Lake Winnipeg: 50°N/98°W: 135 $ng{\cdot}g^{-1}$) than in northern lakes (e.g. Hazen Lake: 81°N/71°W: 4.52 $ng{\cdot}g^{-1}$) (Tomy et al. 1999). In this study, the high concentrations of PCPs measured in Lake Winnipeg were attributed to discharges from the nearby City of Winnipeg, while atmospheric transport may have introduced PCPs into more remote lakes (Tomy et al. 1999). In the U.S., drainage ditch sediments receiving discharge from a PCP manufacturing site had concentration ranges of 1.2-4.0 $\mu g{\cdot}g^{-1}$ (C_{10}-C_{13}: 60% Cl), 0.76-50 $\mu g{\cdot}g^{-1}$ (C_{14}-C_{19}: 52% Cl), and 3.6-170 $\mu g{\cdot}g^{-1}$(C_{20}-C_{30}: 42% Cl) (Murray et al. 1988).

7.2 BROMINATED FLAME RETARDANTS

The two key brominated flame retardants of environmental concern include the polybrominated biphenyls (PBBs) and polybrominated diphenyl ethers (PBDEs). There are 209 theoretical congeners for the PBBs and PBDEs, reflecting the number and position of bromine atoms on the two phenyl rings (de Boer et al. 2000). Commercial use of these chemicals was initially dominated by hexa-, octa-, nona-, and decabromobiphenyls for PBBs and penta-, octa-, and deca-bromodiphenylethers for PBDEs (de Boer et al. 2000). More recently deca-PBB and penta- and deca-PBDE have dominated commercial use. PBB and PBDE flame retardants are used in electronic components and backings of televisions and computers, in textiles and in vehicle seats (de Boer et al. 1998).

Polybrominated biphenyls and PBDEs share physicochemical properties with other organohalogen compounds. They are persistent and lipophilic (high log K_{ow}: >7). The bioconcentration factor of PBDEs may be even higher than those reported for PCBs; in blue mussels (*Mytilus edulis*) the bioaccumulation factor for PBDEs is approximately 1 400 000 x compared to 200 000 times for PCBs.

Brominated flame retardants can be carcinogenic and may disrupt the function of thyroid and steroid hormones (de Boer et al. 1998). In addition, polybrominated dibenzodioxins and polybrominated dibenzofurans can be formed during the combustion of PBBs and PBDEs. Although the toxicity of these products is not well known, they may be comparable to structurally related dioxins and furans (de Boer et al. 2000).

In the early 1970s, public concerns about health and safety following the accidental contamination of dairy cattle feed with PBBs in Michigan led to a reduction in PBB production. PBDEs were introduced as a substitute for PBBs and their production has since increased annually (de Boer et al. 2000). Both PBBs and PBDEs, however, continue to be used around the world (PBBs: 2 $kt{\cdot}yr^{-1}$; PBDEs: 40 $kt{\cdot}yr^{-1}$), unlike chemicals with similar properties that have restricted use (e.g. PCBs) or have been banned from use (e.g. DDT) in North America (de Boer et al. 1998).

Polybrominated biphenyls have been reported in terrestrial and aquatic biota around the world, including North America, Europe and Asia (de Boer et al. 2000; de Boer et al. 1998; World Health Organization 1994). Polybrominated diphenyl ethers have been detected in marine mammals in the Atlantic Ocean; concentrations measured in sperm whales, whitebeaked dolphins, and harbour seals were ~100 $\mu g \cdot kg^{-1}$, ~7 $mg \cdot kg^{-1}$, and ~1 $mg \cdot kg^{-1}$, respectively (de Boer et al. 1998). Although PBDE products are dominated by deca-BDE, both tetra- and penta-BDEs are the most commonly detected in the aquatic environment (de Boer et al. 2000). In biota (fish and marine mammals), tetra-BDE dominates, due in part to greater uptake of less brominated compounds.

Since concentrations of PBDEs have been increasing in the global environment (Gustafsson et al. 1999), more research is required that will address the environmental fate and toxicological effects of these compounds.

7.3 FLUORINATED ORGANIC SURFACTANTS

Perfluorooctane sulfonate (PFOS) has been used as a stain repellent (including Scotchgard^{TM}) in textiles and carpeting, as a water and oil repellant in paper and packaging, and as an ingredient in fire-fighting foams. Other fluorinated organic compounds are used as surfactants, fire retardants, insecticides and refrigerants (Giesy and Kannan 2001).

Although research is currently being conducted on PFOS, little information is available on its physicochemical properties (e.g. vapour pressure or K_{ow}). Perfluorooctane sulfonate is highly persistent; there are no known degradation pathways for this chemical. Unlike PCBs and DDT, PFOS is water soluble. This chemical also tends to accumulate in organisms via nonlipid mechanisms in the blood and liver. Little information is available on the toxic effects of PFOS on biota; some known effects include disruption of intercell communication, membrane transport and energy generation (Giesy and Kannan 2001), and tumour promotion (Renner 2000).

Perfluorooctane sulfonate has been reported in organisms around the world, far from sites of production and use (Renner 2000). PFOS has been detected in grey seals of the Canadian Arctic (plasma: 11-49 $ng \cdot g^{-1}$ wet wt), polar bears in Alaska (liver: 180-680 $ng \cdot g^{-1}$ wet wt), California sea lions (liver: < 35-49 $ng \cdot g^{-1}$ wet wt), and chinook salmon in the U.S. (muscle: 7-190 $ng \cdot g^{-1}$ wet wt) (Giesy and Kannan 2001).

7.4 POLYCHLORINATED NAPHTHALENES (PCNs)

Polychlorinated naphthalene (PCN) compounds are planar compounds composed of two aromatic rings with one to eight chlorines. A total of 75 different PCN compounds exist (Yamashita et al. 2000b). Production of PCNs began in the 1930s but was discontinued in the U.S. and Europe in the 1980s. Since PCNs are relatively inert and thermally stable, they were used as insulation in ships and electrical wires, and as additives in engine oils and capacitors. These chemicals continue to be used in electrical equipment today. They are also released by municipal waste incineration and chlor-alkali plants, and also occur in mixtures of PCBs. Approximately 150 000 t have been released globally (Villeneuve et al. 2000).

Polychlorinated naphthalenes are highly persistent and can bioaccumulate. Congeners can bind to the Ah-receptor in a manner similar to 2,3,7,8-TCDD (Yamashita et al. 2000b).

Detection of PCNs in the environment only began after 1975 when analytical methods were developed and standards became readily available (Yamashita et al. 2000b). Polychlorinated naphthalenes have been detected in several environmental compartments including sediment, water and biota. Concentrations of PCNs in sediment cores from Tokyo Bay, Japan, reflect their history of use since the early 1900s. Sediment concentrations were low during their early use, reached a maximum in the 1980s, and subsequently declined as global use decreased (Yamashita et al. 2000b). Polychlorinated naphthalene concentrations measured in fish from the Great Lakes (1996-1997) reached a maximum concentration of 31 400 $pg \cdot g^{-1}$ wet wt, reflecting both local and global sources (Kannan et al. 2000). Specific congeners that have been measured in surface sediments include the penta-CNs (Yamashita et al. 2000b); the penta- and hexa-CNs dominated in samples of fish (Kannan et al. 2000).

7.5 ALKYLPHENOL ETHOXYLATES (APEs)

Alkylphenol ethoxylates (APEs) are mixtures of homologues, with up to nine ethoxy groups. Nonylphenol ethoxylates make up the largest percentage (80%) of the world market, followed by octylphenol (Renner 1997). These chemicals, first used in the 1970s, are used as surfactants in detergents and shampoos, in paints, pesticides, and plastic products, and may also have been released by the pulp and paper and textile industries. Between 1970 and 1999, more than 0.3 Mt yr^{-1} was used globally (White et al. 1994); in the Georgia Basin more than 11 000 kg of APEs were sold in 1995 (Norecol Dames & Moore 1997; Yamashita et al. 2000a). Global release of APEs is greater than 300 kt per year with as much as 60% of this entering the aquatic environment primarily through sewage effluent (ENKON Environmental Limited 1999). These chemicals are not produced naturally (Government of Canada et al. 1999; Renner 1997).

Compared to their parent compounds, APE breakdown products are more persistent and lipophilic (Renner 1997). Biodegradation involves the loss of the ethoxylate group producing a variety of metabolites that can include short-chain ethoxylates, alkylphenoxy carboxylic acids and alkyphenols. Shorter chain compounds are less soluble; nonylphenol and octylphenol have low water solubility and adsorb to solids (Renner 1997). Nonylphenol and nonylphenol ethoxylates do not strongly partition into gas phase; they have low Henry's Law constant (Government of Canada et al. 1999).

The breakdown products of APEs are more toxic to aquatic life than the parent compounds; nonylphenol is considered 10 times more toxic than its parent compound nonylphenol ethoxylate (Renner 1997). These chemicals can cause endocrine disruption in biota. Although toxicity has not been assessed in marine mammals, APEs can cause vitellogenin induction in male rainbow trout (Lech et al. 1996), decreased gonadosomatic index in female rainbow trout, and decreased body weight in this species (Ashfield et al. 1998).

In recent studies, APEs have been detected in aquatic habitats (Maguire 1999). These chemicals have been measured in sediments within the Strait of Georgia (nonylphenol: 170 t overall) and near the Iona municipal outfall in Vancouver, B.C. (nonylphenol: 30 t), with an estimated half-life of 60+ years (Shang et al. 1999). For Canadian sewage treatment plants, influent concentrations of nonylphenol ranged from 0.7 to 155 $\mu g \cdot L^{-1}$ and in treated effluent concentrations ranged from 0.4 to 13 $\mu g \cdot L^{-1}$. For the U.S., concentrations near discharge sites are generally less than 10 $\mu g \cdot L^{-1}$ (ENKON Environmental Limited 1999). Many European countries have restricted the domestic and industrial use of these chemicals (Renner 1997). In Canada, nonylphenol ethoxylates were declared toxic under CEPA 1999 and as a result, it is recommended that concentrations of these chemicals reaching the environment be reduced (Government of Canada et al. 1999).

7.6 POLYCHLORINATED TERPHENYLS (PCTs)

Polychlorinated terphenyls (PCTs) are diphenylbenzenes. Terphenyl groups can be arranged in *ortho*, *meta*, and *para* positions with different numbers of attached chlorine atoms resulting in a total of 8149 different PCT congeners possible. The high chemical and thermal stability of PCTs have made them useful as fire retardants, plasticizers, lubricants, inks, and sealants (de Boer 2000).

Polychlorinated terphenyls are persistent, have a low volatility, low water solubility, and high bioaccumulation potential. Polychlorinated terphenyls have a toxic potential that is similar to PCBs, although mechanistic studies have been impeded by the presence of contaminating PCBs in PCT mixtures. Lower chlorinated PCTs are more acutely toxic than higher chlorinated PCT mixtures and acute effects in mammals include subcutaneous edema, acneform lesions, swollen eyelids and lips (de Boer 2000).

Polychlorinated terphenyl production started concurrently with PCB production in 1929 by Monsanto Chemicals in the U.S. Other countries that later produced PCTs included Japan, Germany, Italy and France. Total production of PCTs (1955-1980: 60 000 t) has been approximately 15-20 times lower than PCB production. Most countries stopped PCT production by 1980 (de Boer 2000).

Polychlorinated terphenyls have been detected in sediments, water, fish and humans (Gallagher et al. 1993). Polychlorinated terphenyls have also been detected in white-beaked dolphins and harbour porpoises in the North Sea (Wester et al. 1996) and in sperm whales (de Boer et al. 1998). Since PCT mixtures are complex and individual congeners are not commercially available, congener specific analysis of these chemicals has been limited.

Despite their physicochemical resemblance to several banned organochlorine chemicals, many relatively new (unregulated) chemicals continue to be released into the aquatic environment from anthropogenic sources. These include the polychlorinated paraffins, brominated flame retardants, fluorinated organic surfactants, polychlorinated naphthalenes, alkylphenols and polychlorinated terphenyls. The effects of these chemicals on killer whales are not known.

Table 19. Many new, poorly regulated chemicals present an environmental risk since they are highly toxic and have high bioaccumulation potential and persist for a long time in the environment.

Minimally-Regulated Chemicals	Global Releases	Uses/Sources	Environmental Persistence	Bioaccumulation Potential	Toxicity
Polychlorinated Paraffins Short Chain (10-13 Carbons) Medium Chain (14-19 Carbons) Long Chain (20-30 Carbons)	300 kt/yr	• flame retardants • paints and sealants • additives in oil • placticizers	**High**	**High**	**High** short chain (C10-C13) • kidney and liver damage
Brominated Flame Retardants Polybrominated biphenyls (PBBs) Polybrominated diphenyl ethers (PBDEs)	 2 kt/yr 40 kt/yr	• electronic equipment (televisions & computers) • textiles • sewage sludge	**High**	**High**	**High** PBB: tetra/hepta PBDE: tetra/penta • effects liver and thyroid
Fluorinated Organic Surfactants Perfluoro-octane sulfonate	na	• stain repellents (Scotchgard) on textiles, carpeting • fire-fighting foams	**High**	**High**	**Moderate** • can promote tumors
Polychlorinated Naphthalenes 75 Compounds (1-8 Chlorine Atoms)	150 kt/yr	• insulation (ships and wires) • additives in engine oils • capacitor dielectrics • contaminants in PCB mixtures	**High**	**High**	**High** hexa, hepta, penta PCNs • Ah-receptor mechanisms
Alkyl-Phenolic Polyethoxylates degradation products: nonlyphenol octylphenol	300 kt/yr	• surfactants in detergents • surfactants in paint • pulp and paper production • sewage treatment plants • pesticide emulsifiers,	**Moderate**	**Moderate**	**Moderate** • endocrine disrupting • reproductive impairment
Polychlorinated Terphenyls	2.4 kt/yr 1955-1980	• fire retardants • placticizers • inks, sealants	**High**	**High**	**High (similar to PCBs)** • endocrine disrupting • reproductive impairment

8.0 Conclusions

Despite restrictions on their use, many classes of toxic and bioaccumulative chemicals, including PCBs, DDT, and toxaphene, continue to be detected in the coastal environment of B.C. and Washington. Although concentrations of many of these contaminants declined following the implementation of regulations, sediment concentrations of several of these chemicals have stabilized during recent years as a result of recycling in the water column and continued inputs from old sources. Several chemicals that continue to be used in developing nations may be transported through the atmosphere to coastal B.C. and Washington. Locally, contaminated landfills and effluent discharges from industrial and municipal sources may continue to introduce small to moderate quantities of these chemicals to coastal marine waters.

Although clean-up of contaminated sediments has been initiated at some B.C. and Washington sites, such measures are costly and time-consuming. Sediments contaminated from past activities are likely to continue to mobilize contaminants into coastal food chains, thereby contaminating the prey of southern resident killer whales. Sediments at several sites in the Strait of Georgia and Puget Sound exceed sediment quality guidelines for many contaminants.

In addition, many other chemicals including currently used pesticides, polycyclic aromatic hydrocarbons and heavy metals, are released into the atmosphere or into the marine environment through stormwater runoff and wastewater discharges. While the non-bioaccumulative chemicals are unlikely to present a significant direct risk to the health of killer whales (e.g. most metals, PAHs, dioxins and furans), they may adversely affect killer whale prey populations and their habitat quality.

Although many banned chemicals and those with recognized environmental effects are monitored, many new chemicals that have similar properties to these chemicals are not. Several relatively "new" chemicals including PBBs, PBDEs, polychlorinated paraffins, polychlorinated terphenyls and perfluorinated organic surfactants, are increasingly being detected in biota and sediments around the world. Given the introduction of up to 1000 new chemicals each year into the environment, it is exceedingly difficult to characterize the risks of adverse health effects in killer whales that are associated with acute or chronic exposures. Alone, or acting synergistically with other chemicals, these compounds may present a risk to the southern resident killer whales that feed in the industrialized coastal waters of southern B.C. and northern Washington.

Persistent, bioaccumulative and toxic compounds present in discharge from sewage, agricultural/urban runoff, landfill leachate and in sediments will continue to contaminate coastal food chains and killer whale prey. In addition, the atmospheric transport of persistant, bioaccummulative, and toxic chemicals from distant sources ensures a steady delivery into both the local environment and into the open North Pacific Ocean, where the principal prey (salmonids) of resident killer whales grow and feed. An important component of southern resident killer whale habitat faces significant risks over the coming decades: increased urbanization and industrialization of the Georgia Basin-Puget Sound-Juan de Fuca Strait will lead to increased stresses on the health of this transboundary ecosystem. Exposure to both "old" and "new" chemicals may affect the health of killer whales through toxicities at the level of their endocrine and immune systems. Such toxicities may be manifested in the way of reproductive impairment, developmental abnormalities and increased susceptibility to disease. Further research into contaminant transport and fate in the B.C.-Washington environment and effects of toxic chemicals on the health of marine mammals is needed, with due consideration to the other stresses faced by killer whales: vessel traffic (noise and stress) and diminished food supply.

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